Prof. Simon Schaffer: Isaac Newton (1684)

[Sound of ticking clock]

Hello, and welcome to *Travels Through Time*. In each episode of this podcast, we invite a special guest to take us on a tailored tour of the past. *Travels Through Time* is brought to you in partnership with *History Today*, Britain's best-loved serious history magazine. You can read articles relating to this podcast and more about our guests at historytoday.com/travels. There is also a special subscription offer for *Travels Through Time* listeners - three issues for just £1 each.

Peter Moore: Hello, I'm Peter Moore and this the fourth episode of *Travels Through Time*, where we invite a special guest to travel back into the past to three distinct scenes within the confines of a single historical year. So far, we've journeyed to 1841 with Sir Michael Palin in search of that ship, HMS Erebus. We've followed the Suffragette Movement right to the gates of Buckingham Palace, in 1914, with Dr Diane Atkinson. We've delved deep into Cherokee country, in 1776, with the Australian historian Dr Kate Fullagar. If you want to listen back to any of these, they're all available right now and, of course, you can get the first news of every new episode simply by subscribing to our feed. For our fourth time traveller, we have one of Britain's very best historians for you. Simon Schaffer is Professor of the History of Science at the University of Cambridge. He has had a long, distinguished and swashbuckling academic career and publishing on a great range of subjects, from astronomy and the problem of longitude to mesmerism and the birth of evolutionary theory. His co-authored book, *Leviathan and the Air-Pump*, which examines the origins of The Royal Society and the quest for scientific truth in the mid-17th century, is generally regarded as a classic. I recently met with Simon at the Whipple Museum of the History of Science in the centre of Cambridge. He had taken me up on the offer of a trip into the past and had opted to venture back 335 years from 2019 to 1684 and to one of the most thrilling moments in the entire history of science. We'll get to that story soon enough but I started off by asking Simon what kind of year 1684 really was.

Prof. Simon Schaffer: 1684, looked at from many points of view, is a rather unlikely year to choose because it was so extraordinarily unpleasant. Where I want to go, in 1684, is London, and then Cambridge, and then London again. First of all, the winter of 1684 was the coldest winter this country has ever experienced.

Peter Moore: What does that mean in real terms? Are we thinking of ice on the Thames and the usual story of the frost fairs?

Prof. Simon Schaffer: This is the first frost fair and in January 1684, the river froze from bank to bank and all the way down to the mouth and allegedly, well out to sea. Right through the early months of 1684, England was freezing.

Peter Moore: Could this be used in a metaphorical sense as well? Was there a sense that things were not quite right at this time?

Prof. Simon Schaffer: Yes, this is a country in major political crisis. The previous year, there had been a plot, now called the Rye House Plot, to assassinate the King and his brother. The King was Charles II. The atmosphere in London at the start of '84 is of imminent real threat. The King is ill and the threat of Catholic succession is becoming more and more imminent. The country is experiencing this unprecedently bad weather of this freezing winter and very late spring. It's an agricultural country, overwhelmingly, so the delay in the growth of crops and, by implication, the delay in the harvests would have had catastrophic effects on agricultural incomes, on rent and on the national economy. At the same time, there's a major military and political threat from overseas from the strongest military power in Europe, France, where Louis' XIV's government in Paris had essentially banned the reformed religion and this really seemed to threaten something like European war.

Peter Moore: It feels very tense, in a temporal sphere at least. We've got an elderly monarch and a coming national crisis. What does that remind you of? I suppose it's something that we can perhaps empathise with a little bit today. Within this, we'll start your travels, I think. What's going to be your first scene?

Prof. Simon Schaffer: On a Wednesday evening in January of 1684, three absolutely remarkable men met - I'm not sure where - to discuss one of the most important problems in astronomy and therefore, by implication, one of the most important problems in knowledge of the time.

Peter Moore: Who are these three men?

Prof. Simon Schaffer: The three men are, in order of descending age, Christopher Wren, who was in his early 50s. Wren was architect and surveyor to the King.

Peter Moore: So we can take it that Christopher Wren, in January 1684, was a rather busy person. Who was he meeting?

Prof. Simon Schaffer: He was meeting two younger men. One was Robert Hooke, who was 48 and just a few years younger. Robert Hooke was Architect and Surveyor to the City of London. Wren was Surveyor to the King and Hooke was Surveyor to the City. Hooke was also, extremely importantly, Curator of Experiments for The Royal Society of London. Every Wednesday, The Royal Society would meet and normally, Robert Hooke would produce experiments for the fellows of The Royal Society and that was his job as paid curator. These two comparatively elderly men, round about 50 years old, are meeting a very much younger man, Edmond Halley. Halley was 27, which is very young. He'd already been a world traveller and he'd commanded a naval expedition into the South Atlantic to Saint Helena in the 1670s. He'd travelled to Danzig, or Gdańsk, on the Baltic to inspect Europe's most important astronomical observatory there. In 1680 and 1681, Halley had toured Europe and brought back to England, in 1681, a treasure trove of astronomical observations, particularly observations of comets and distributed these observations to eminent astronomers in England.

Peter Moore: As we know Wren through his architecture in the City of London, we obviously know Halley as he's been immortalised through the name of his comet. Was it not two years earlier that Halley's comet was first observed, you would imagine, by Halley himself? Is that right?

Prof. Simon Schaffer: Yes, in 1682, what we now call 'Halley's Comet'. They, of course, did not call it Halley's Comet.

Peter Moore: No, I imagine they didn't.

Prof. Simon Schaffer: It flashed across the sky and it was extraordinarily bright. It drew a great deal of astronomical attention but in public consciousness, comets signalled disaster. The association between the unusually bright and rapidly moving comet, seen in the 1680s, and the political crisis that was wracking the country at that time...

Peter Moore: And the weather, indeed.

Prof. Simon Schaffer: ...and very bad weather, these were surely signs put into heaven by God that something was deeply wrong. Shakespeare says, 'When beggars die, there are no comets seen. The heavens themselves declare the death of princes.'

Peter Moore: Wow! We have here, I think, the perfect ingredients. We have these new philosophers, who've maybe got the Shakespearean mood music in the background but what were they meeting on this particular day to talk about? Why were they there? If we were imagining them huddled around their steaming coffee mugs, that they might be, what were they talking about?

Prof. Simon Schaffer: What they were talking about was how the heavens move: the great question of astronomy. In the 1670s and '80s, both Hooke and Wren had devoted a lot of work trying to make sense of how and why planets move around the Sun but what they could not see clearly was how that force works and whether you could match the best astronomical observations of planetary positions to some rational force that the Sun exerts on the planets. In other words, they were going to be talking about, on this Wednesday evening in January of 1684, what's the relationship between the force the Sun exerts on the planets and the paths the planets describe.

Peter Moore: Can we imagine Wren, as the elder statesman of this trio, leading the conversation or cajoling the others because there was some incentive that he had for them, was there not?

Prof. Simon Schaffer: Yes, what Wren said was, 'All three of us agree that there is a force that the Sun exerts which tails off with distance from the Sun. We all agree that it tails off as one over the square of the distance from the Sun. It's an inverse square law force. If you're twice as far from the Sun, the force is a quarter as strong. If you're three times further away from the Sun, the force is a ninth as strong and so on.' They knew that and they all agreed about that. They also agreed that the paths of the planets around the Sun are ellipses and not circles.

Peter Moore: A squashed circle.

Prof. Simon Schaffer: A sort of a squashed circle. They knew those two things because they were disciples of perhaps the greatest early 17th-century astronomer, Johannes Kepler. What they could not work out was how you could reconcile those truths about planetary motion with this idea that the Sun is somehow pulling on each of the planets with this strange force.

Peter Moore: So this is the substance of the conversation which is going on in the coffee shop, should we say?

Prof. Simon Schaffer: Were I sitting there in one corner, cloaked, silent and not wishing to intervene, what would be fascinating would be to listen to how that conversation went because during the conversation, Christopher Wren, the oldest and by far the wealthiest of these three men, offers a prize. He offers a prize of no less than 40 shillings, which is well over £1,200 in modern money, to either of his other friends that if, in two months from this date, they can show that if the force is an inverse square law force, then the planets must move in ellipses.

Peter Moore: You say that in the whole history science this is one of the important wagers. It also strikes me as a really good New Year's resolution, if we can put it that way. This problem, which has obviously been frustrating the greatest minds in the country for so long, has to be solved. They feel like they're close to solving it. If you're watching them, do you think there is a bit of a bright gleam in Hooke's face or do you think Halley fancies his chances? Would they be rivals in the scheme, do you think, or would they be working together in unison?

Prof. Simon Schaffer: There's a rivalry. Hooke had form. He had a track record of claiming to have discovered, first, all sorts of inventions and discoveries in natural philosophy, mechanics, experiment, clockwork, astronomy and so on.

Peter Moore: Of course, we know him for the microscope.

Prof. Simon Schaffer: That others, seemed to him, wrongly to have claimed to have invented. One of the things we know that happened during this conversation in the coffee house was that Hooke told the other two that he could derive or discover all the laws of planetary motion. So it seems to me anyway, that's why I want to be there on this evening, that Wren reacts to that with this offer. He's basically calling Hooke out. Hooke says, 'I can demonstrate and discover that on the basis of an inverse square law force, you can derive all the motions of the planets, the whole principle of the world's system.' Wren, presumably, responds to that well and says, 'Here is an offer. For 40 shillings, which will be offered as a book (we're not sure what book Wren had in mind), if in eight weeks from now you can do that, then the prize is yours.' Halley is the junior partner and what Halley has been doing is making observations of the heavens; of comets and of the position of the moon.

Peter Moore: So we've got this dynamic between very different characters, this enormous question and the slightly sordid enticement of financial gain, which has often been used in the history of science to encourage people and we think, probably, mostly of the longitude prize of the next century when that's actually coming from the government. In this case, we're talking about a personal bet between friends and so I imagine there's a bit of personal pride involved here.

Prof. Simon Schaffer: I think that's absolutely right. I think that Wren's wager, which is really what it is, is designed to press Hooke's claim and to test it out. What I think really mattered, and this is going to explain my choice of where we go next, is that you need mathematics to solve this problem. For Hooke, the problem, in principle, could be solved by experimental modelling. Hooke's basic idea was that bodies orbit - the Earth orbits the Sun - through a combination of motions. The Earth is, on the one hand, if you think about it, falling towards the Sun by some kind of attractive force and at the same time, it's moving at right angles to that path because it has its own motion under a certain speed. The combination of those two movements, falling towards the Sun and moving under its own inertia, as we would now say, produces the path. What Hooke had proposed, much earlier, was that if you could build, for example, a kind of pendulum machine, you could actually model that sort of movement. For Hooke, the dominant science is machinery and that meant that the kind of maths that they would set out to use was rather simple. It was adequate enough to describe how a machine works but the intuition that Wren and, clearly, Halley begin to have is that something much more complex than mathematical mechanics will be required to solve the problem of the motion of the planets.

Peter Moore: I think the word complex is a good one to leave lingering in the air over this conversation as we slip away into our second scene because it's quite the contrast if we imagine we're in the busy streets of London there. We're going to somewhere else. Where do you want to go next?

Prof. Simon Schaffer: Next, I want to go to Trinity College, Cambridge, which is the home of the Professor of Mathematics, Isaac Newton. Isaac Newton was, in 1684, 41 years old. He was already a man of great reputation, certainly in mathematics and optics and much less so in mechanics or astronomy. The reason why our friends in London would have known him was that back in the 1670s, Newton had a furious fight with Hooke in person and by correspondence about the laws of light and colour. Newton had met Christopher Wren on a number occasions. He'd certainly discussed with Wren the problem of how the planets move and Halley met Newton, which seems very plausible, two years earlier in 1682 because when Halley got back from his European tour, he passed on to Newton his observations and others' observations of comets. So some of them, certainly Halley, Wren and to a certain extent Hooke as well, would have been aware that up in Cambridge, two days' horse ride from London, was a man who was also perhaps working on this problem.

Peter Moore: It's not only the difference between London and Cambridge, which you might term the big and imperial capital it would become later and the university town, but Newton is a different character. He's a brilliant theoretical mathematician. We know that now and they probably knew that then as well but was he a cold mathematician? There's lots of talk about him being very puritanical. He wouldn't be going out to coffee shops, for example. Would he go to the theatre? We're not sure about that with Newton.

Prof. Simon Schaffer: No, Newton is not a party animal.

Peter Moore: No, he's not a party man, is he?

Prof. Simon Schaffer: He's relatively reclusive, especially at this period. It is, for example, extremely telling that hardly any letters survive in the first half of the 1680s, either to Newton or from him. This is a period when Newton was working in comparative solitude and working extremely hard, as we know from the manuscripts of Newton that have survived, on a huge range of topics. Newton was working on alchemy in the spring of 1684 and his alchemical notebooks are full of exclamations of great success. 'I made Jupiter fly on his eagle,' says one of the entries. We actually aren't quite sure what that means.

Peter Moore: Well, it's a good day at work.

Prof. Simon Schaffer: It's a good day at work if you see that.

Peter Moore: There is almost an element of the detective about Newton as well and there's an intense intellectual energy which we completely get. What happens in August 1684? Does he get wind of this?

Prof. Simon Schaffer: What happened, which is why I want to be in his room in August of 1684, is that Edmond Halley came to visit. It might have occurred to you that this is quite a long time after January of 1684.

Peter Moore: It doesn't bode well for Hooke and Halley's researches in the meantime.

Prof. Simon Schaffer: No. Halley had a good reason to delay because in April of 1684, his father was found drowned in a river near Rochester in Kent. The London gossipmongers and pamphleteers reckoned that Haleys' dad had been murdered and the reason they reckoned he'd been murdered was that he was a warder of the Tower of London. He'd been on duty, back in 1683 the previous year, when the Earl of Essex allegedly topped himself. The London pamphleteers reckoned that Essex had not killed himself but he'd been killed on the orders of James, Duke of York.

Peter Moore: So whilst Halley is supposed to have his head up in the heavens and putting a bit of order into that, meanwhile on Earth, things are getting a bit more complicated.

Prof. Simon Schaffer: Yes, terrestrial politics erupt into Halley's life. He was living up in Islington, which was then a little village a bit of a way north of London. He had his own observatory, his wife and his telescopes but these events, the death of his father, completely disrupted his life. His father was fabulously wealthy. In fact, Halley's income was basically an allowance from Dad. He was a trustafarian. What Halley's father's death meant to him was that he suddenly inherited really quite a lot of money and property in London and he moved down from Islington to Aldersgate in the Barbican, bringing his wife with him, but he must have become wrapped up with lawsuits, conflicts and bad political struggles. It's not until the summer of '84 that Halley would have had any free time at all.

Peter Moore: I suppose he escaped to come to Cambridge, maybe.

Prof. Simon Schaffer: He had family connections near Cambridge, in Huntingdon, and so maybe he was visiting them but under any circumstances, we know, because Halley says so, that in August of 1684, he came to visit Isaac Newton and asked Newton Wren's question. Halley asked Newton, in Newton's rooms, 'If the force connecting the Sun to the planets is an inverse square law force, what is the shape of the path of the planets?' Newton says, 'It's an ellipse.' Halley, understandably, says, 'Can you demonstrate that?' Newton says, 'Yes, I can and, in fact, I've done it.' Halley says, 'You wouldn't mind giving me a copy of this proof, would you?' Newton says, 'As it happens, I've mislaid it but what I'll do is I'll search around. You go back to London and I'll send it to you.'

Peter Moore: This is an incredibly nonchalant way of revealing to a friend that you happened to have solved the greatest mathematical puzzle of the time but it's upstairs somewhere in a drawer.

Prof. Simon Schaffer: I just can't put my hand on it.

Peter Moore: It either sounds like an implausible excuse you might get in a school somewhere or that Isaac Newton was really that kind of careless, bad record keeper genius. Is that right?

Prof. Simon Schaffer: He certainly wasn't a bad record keeper, which is one of the reasons I think he wasn't telling the truth on this occasion.

Peter Moore: Do you think he was playing for time?

Prof. Simon Schaffer: I think he was playing for time. There's something very important about Halley's question which is that we now know that, until this point, Newton has left us no indication whatsoever that he was using this kind of model to make sense of planetary motion. Newton had a completely different idea, in the early 1680s, of how the planets move. In his notes and letters, he describes planets in orbit around the Sun being pulled towards the Sun and, at the same time, trying to move away from the Sun. If you think about it, if you whirl a stone in a sling in a circle, you feel the stone trying to move away from you. The string becomes taut.

That was called, at this time, centrifugal; a force moving away from the centre. What Newton was saying is that it's the balance between the centrifugal force away from the Sun and the force towards the Sun, the balance, produces the orbit. That is very different from the conversation of January 1684 between Hooke, Halley and Wren. What they were saying was that the path is defined by a movement towards the Sun but a movement at right angles to that path, an inertial movement. So when Halley asks Newton the Wren question, 'If the force is an inverse square, what's the shape of the orbit?' and Newton says, 'It's an ellipse and I can demonstrate that,' this is clearly a prompt to Newton to start rethinking his whole model of how planets move and what forces are acting. He says to Halley, 'I just can't find the demonstration,' because thinking extremely fast, he begins to realise the possibility of reorganising his whole model of celestial motion. That's why I want to be in that room.

Peter Moore: Do you think it would be a scene charged with excitement for Halley? You get these moments, I suppose, when you get a conjunction - a person with an idea or something like that - and it seems, at this particular moment, that a process has been ignited probably just by Halley's visit. So to witness that would be to see...

Prof. Simon Schaffer: Yes, it would be quite extraordinary.

Peter Moore: It's almost like a Genesis moment, isn't it?

Prof. Simon Schaffer: Halley later, reminiscing about this encounter, says, 'I was the Ulysses who produced this Achilles.'

Peter Moore: Well, let's leave Ulysses and let's leave Achilles. I want you to go on to your third scene and I think this is perfectly poised. What's happening next?

Prof. Simon Schaffer: The third scene is much better documented than either January or August of 1684. This is 10th December 1684 at Gresham College in London. I'm at a meeting of The Royal Society, not in a coffee house but in the meeting rooms of The Royal Society at a very formal Wednesday evening meeting. There is a very grand chair at one end of the room and in the chair is sitting the President of The Royal Society, Samuel Pepys. Pepys was President of The Royal Society and he'd been president for about two weeks. He was a fantastically eminent and distinguished civil servant. He was in charge of the British Admiralty and he was essentially the head of the Royal Navy at this time. He was a very close ally of the King and of the King's brother, the Duke of York, and because of those connections and his interest in basically almost everything, as we know from his diaries, he'd been elected President of The Royal Society. Halley was a member of the Council of The Royal Society and one of its chief delegates. Halley appears at this meeting and tells The Royal Society that he's just visited Newton in Cambridge for the second time. Sometime in November 1684, Halley has gone back to Cambridge to see Newton again and he reports that he's received, through an intermediary, a copy of an amazing document from Newton which is called *Of Motion* (De Motu in Latin). This document is going to be a revolutionary text. It's the very first, publically distributed version of what will become, in the next 18 months, one of the greatest - if not the greatest - book in the history of science, Newton's *Principai Mathematica,* the Mathematical Principles of Natural Philosophy. This is a very dramatic moment in the history of science. This is the presentation by Edmond Halley to The Royal Society of the very first draft sections of this extraordinary book. Sometime between August of 1684, when Newton couldn't quite put his hand on this proof, and November/December of 1684, Newton had moved from not being able to find his proof to beginning to turn the proof not just into a proof of the relation between the inverse square law force and the path of the planets but a mathematical theory of the whole universe.

Peter Moore: Just to explain how much excitement this must have generated, astronomy really was seen as preeminent among the sciences at this time, was it not? This was the greatest question within astronomy and here, in The Royal Society meeting, we have someone presenting themselves with an answer. That is about as exciting as it could possibly get. We're in the scientific revolution, of course, as we call it now. Of course, they didn't talk about it in those terms then. There are a lot of incremental changes happening in all sorts of disciplines but this really is something else, isn't it?

Prof. Simon Schaffer: Yes, this is a set change in all sorts of ways...

Peter Moore: Paradigm.

Prof. Simon Schaffer: ...in what the relation between mathematics and cosmology and, by implication, what the relation between mathematics and natural knowledge might be capable of becoming. That was recognised very quickly by Halley, of course, who'd seen this treatise in Newton's handwriting and there is, in fact, a copy in Halley's handwriting of the first version of this treatise. Halley was going, in fact, to become Newton's editor. Over the next 18 months, it was Halley who, by weedling, seduction, brilliant diplomacy and very careful personnel management, managed to extract from Newton, often against Newton's will, a three-volume book that completely revolutionised astronomy, cosmology and natural philosophy. That it was a revolutionary work became clear extremely fast and so, for example, by 1685/86, predictably, Robert Hooke claimed that he'd thought of the idea first *[laughter]*. Once the news that he'd thought of all this first reached Newton in Cambridge, Newton went ballistic, if you'll pardon the expression. He went so ballistic that Newton decided, initially, that he wasn't going to publish the final volume of the book and perhaps not the book at all, but certainly not the final of the three volumes of the book, because what he called 'smatterers in mathematics' (by which he meant Robert Hooke) were claiming the credit for what he and he alone had been able to do. Remember that for Newton, this is not just a priority fight. It's a fight about revealing the ways of God to men. This is a theological, moral, ethical, spiritual issue. This is all about the right way of interpreting God's purposes and for Newton, what became eventually, by 1686, *The Principia Mathematica* was the revelation of how God had made, arranged and designed the world.

Peter Moore: Let's just linger for a moment in the lecture hall at this gathering with the fellows of The Royal Society. Let's look around. What can we see? I suppose there's Halley standing delivering the news that the Professor of Mathematics at Cambridge has provided proof of a new theory to explain a great problem. Do you think this would be immediately exciting? Newton is someone with form, isn't he? He's someone who has got a track record of changing the way people think about the world.

Prof. Simon Schaffer: Yes, and what is really interesting is that we have the journal of The Royal Society. We actually have the minutes of this meeting and so we know what happened. The Royal Society said, 'Newton has to establish his priority and the way to do that is to publish this work.' At once, The Royal Society begins to put pressure on Newton, through Halley, to extract from Newton this treatise on motion and the system of the world, so that Newton can establish his rights to this great discovery. On the other side of the room is Robert Hooke. Robert Hooke has spent the immediately previous bit of the meeting showing the fellows of The Royal Society a drawing of a geometrical instrument that he's invented and promising to bring in examples of this instrument. The contrast between Hooke's world and Newton's world could not be clearer.

Peter Moore: Completely on display that day, isn't it?

Prof. Simon Schaffer: What Hooke is doing is saying, 'What I'm brilliant at is designing machines and instruments, and mathematical instruments at that.' Halley gets up and says, 'I've just been to Cambridge and I've seen Newton and I've seen this treatise that he's written. It's extraordinary.' The Royal Society says, 'He's got to publish it.'

Peter Moore: So really, it's just a chain of challenges throughout the year, isn't it? From the very small gathering of friends, where there are very small personal rivalries and then we get Halley's visit to Cambridge. There is then this challenge which he might have, very subtly, put to Newton in a very clever way. Finally, it's risen to the great court of scientific opinion, if you want to put it in those terms, and it's another challenge. At each stage, Newton rises and produces. Tell us a little bit about the *Principia*.

Prof. Simon Schaffer: After this meeting on December 10th, Newton threw himself into one of the truly amazing, perhaps even miraculous, periods of scientific hard work. A myth has grown up that Newton had all the ideas that are in the *Prinicipia* when he was in his 20s, back in the 1660s, and then, for some reason, delayed for 20 years. That's complete rubbish. The *Principia* was put together not from scratch but from a very, very primitive basis in about two years. The *Principia* was finished 15 months after Halley brought the news to London in December of 1684. That's amazing!

Peter Moore: So it's a furious, creative period. There are stories of him standing up at his desk, aren't there?

Prof. Simon Schaffer: It involved trying to coordinate two closely related projects because the *Principia* is not just one thing. On the one hand, in the first book of the *Principia*, which is called *The Motion of Bodies*, what Newton does is to lay out the basic abstract mathematical principles that govern the motion of all bodies whatsoever and to show how to derive from forces the paths that bodies will follow if forces are being exerted on them. His idea in Book One is that you're to imagine all of this happening in absolutely empty space. In the second book, he then imagines what would happen if space is not empty but full of some kind of fluid that would disturb the motion of bodies and he demonstrates, in the second book of the *Principia*, that if that was true, then we would not see what we see in the heavens and so it must be the case that most of the universe is empty. There's hardly any matter in the world. Later in his life, he'll say that all the matter in the world can be contained in a nutshell. In the third and final book, which he called *The System of the World*, the book that he was going to suppress because he was so angry with Robert Hooke's claim that he, Hooke, had thought of all this, Newton gives the numbers. That was part of his revolution. What Newton had done, in the 1680s, was to accumulate in his room, in Trinity College, data from all over the world: from Cape Horn; from Vietnam; from all across Europe; from the Caribbean; from the slave colonies in the Americas, where he had friends who grew tobacco; all over the world, he gathered numbers. These were the position of comets; the position of planets; the position of the moon; the heights of tides; the length of pendulums in pendulum clocks. All of these numbers are in that final section of the *Principia* and what Newton reckoned he'd shown was that on the basis of the abstract principles in Book One, he'd predicted all those numbers.

Peter Moore: So Book Three just rounded the theory into practice.

Prof. Simon Schaffer: Yes, and vice versa.

Peter Moore: The *Principia* is not an easy read, is it?

Prof. Simon Schaffer: It's not designed to be an easy read. There's an absolutely magnificent comment by Halley to Newton when Halley is negotiating with Newton to try and get the manuscript out of the Cambridge don, which is, 'Please don't leave out Book Three because that's what will attract your readers.' That may be true but this is not a book that had a huge number of readers.

Peter Moore: Well, I say that mostly to give me an excuse to bring out my favourite quote about the *Principia*, which is one I'm sure you know very well, of John Conduitt and he says, 'There goes a man who writ a book that neither he nor anyone else understands.' This is from people watching Newton walk around the streets of Cambridge. Whether it's apocryphal or not, I don't care because it really suggests the idea of people pointing at Newton from a distance because there's this person who's done something absolutely extraordinary.

Prof. Simon Schaffer: But we don't understand what it is.

Peter Moore: No, that we don't understand what it is and I suppose that's a feeling that we can empathise with when we listen to a lot of science being described to us today *[laughter]*. I suppose that's a really good place to bring our travels to a close in Gresham College, as this wonderful, intellectual project is about to come underway. We've seen the genesis of an idea, from very modest beginnings into something which is becoming formalised and which is going to explode and be talked about for years later. You know the Alexander Pope famous couplet. Do you want to say it?

Prof. Simon Schaffer: 'Nature and nature's laws lay hid in night; God said, "Let Newton be" and all was light.'

Peter Moore: We've got a few supplementary bits of business at the end of this time travel to get through on the agenda. First of all, because we're coming back to 2019 now, I'm going to allow you to bring one memento from your time travels with you. What would you like to bring along?

Prof. Simon Schaffer: I think what I'd like to bring along is a document that I actually know exists because I've seen it and so it made it from 1684 to 2019. It's the large document that Newton wrote some time over the winter of 1684/85, which is the first book concerning the motion of bodies. Newton was a Lucasian Professor, so he had the job that Stephen Hawking would later have, for example, and the rule was that each year he had to deposit a copy of his lectures in the university library, whether he'd given them or not. For 1684, the lectures that he decided to deposit were his first version of the whole of the first book of the *Principia*. That's, by far, the most impressive group of lectures that any Cambridge professor has ever deposited anywhere and I'd like to be the owner of that document. Perhaps that's a bit selfish but as a symbol, as well as a reality, of the rapidity with which Newton moved from not being able to find the proof, in August of 1684, to producing one of the most important books ever in science, in the spring of 1686, that document is a remarkable testimony to what it's possible for humans, adequately equipped with enough genius, to achieve even in a very brief space of time. It's a huge consolation to me that Newton did not do this when he was a budding genius in his early 20s. He did it at a mature age, when he was middle-aged, in a rush, driven as he was, but with a lot of his life behind him.

Peter Moore: I think that's a wonderful memento to bring back. We'll put it in the glovebox of our time machine and whizz back to 2019. Are there any books you'd like to guide people towards if they'd like to learn a little bit more about this story in the library? Where would you send them to?

Prof. Simon Schaffer: There are two really good biographies of Newton that deal with this kind of process and the events of 1684. One is a longer book by R S Westfall called, magnificently, *Never At Rest*, which is a biography of Newton that goes into great detail and is actually very readable. There is a shorter, accessible and beautifully written biography of Newton, published by Reaktion Books by Niccolò Guicciardini, which came out very recently, very accessible and I'd strongly recommend it.

Peter Moore: Well, we will leave it there. Thank you very much, Simon Schaffer, for telling us about probably the most magical of all the mathematicians.

Well, that was me, Peter Moore, talking to Professor Simon Schaffer at the Whipple Museum in Cambridge just the other day. It seemed a fitting place for the conversation with Isaac Newton's old chambers at Trinity College just a short walk away. If you enjoyed this episode, then please do leave us a comment. We'd love to hear from you and you could subscribe to get notifications of our next travels as they become available. We'll soon be visiting Ancient Greece to meet the philosopher Socrates and 10 Downing Street in London in that dramatic and consequential month, May 1940. That's to visit Winston Churchill, of course. So plenty to listen out for in the weeks ahead but from me, and for now, that's it. So thank you very much for listening.

[Outro music]

Paul Lay: I'm Paul Lay, the editor of *History Today*. On our website, you'll find articles, written by experts, relating to Simon Schaffer's podcast. You can read Michael Hunter on the fate of Robert Boyle, Harold Hutchison on Christopher Wren or Patricia Fara on Elizabeth Tollet, contemporary of Isaac Newton. Links to all of these pieces can be found at www.historytoday/travels and, of course, there are many more articles on every aspect of the past in *History Today*, the world's leading serious history magazine.

[Sound of ticking clock]

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