Numberphile Podcast Transcript

Episode: Beauty in the Messiness - with Philip Moriarty

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Experimental physicist Phil Moriarty works with temperamental microscopes and individual atoms. Today's topics include Ireland, mathematics, failing at university, microscopy, academic gripes... and music.

Professor Moriarty's university page - including links to some of his papers

Phil's book: When the Uncertainty Principle Goes to 11: Or How to Explain Quantum Physics with Heavy Metal

Some of Brady's videos with Phil

The Golden Ratio music video

Phil's blog

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[Gentle piano music]

Brady Haran [BH]: Today's guest is experimental physicist Philip Moriarty. Phil's based at the University of Nottingham and works at the smallest of scientific coalfaces, manipulating individual atoms in microscopes that, well, they're probably unlike any microscope you've ever seen. Now I've been making videos with Phil for something like ten years mainly on my physics channel Sixty

Symbols but Phil has contributed to a smattering of Numberphile videos, perhaps most memorably a heavy metal song about the Golden Ratio.

[Mastodon-esque heavy metal music fades in]: Irrational! Real but uncountable! Non-transcendental!

[music fades out]

BH: Anyone who's seen Phil's videos will know he's got a strong Irish accent. So I started by asking him, well, a little bit a bout that.

[gentle piano music]

Philip Moriarty [PM]: I was born in London… in 1968 in Ealing and moved to Ireland, my parents moved to Ireland [chuckles] when I was four.

BH: Were your parents Irish?

PM: My mother is Irish, my dad is a Geordie.

BH: Oh, right.

PM: Yeah.

BH: So that's someone from New Castle for the people who don't know what a Geordie is.

PM: Yeah, yeah. And he maintained that accent the whole time he was in Ireland to the point where I had friends if they were there they'd say, don't leave me alone in a room with him, I can't understand a word he says.

BH: It's interesting 'cause I've always thought of you as this like super super

Irish guy, like, you know…

PM: [laughs]

BH: Cut you and you'd bleed green.

PM: [laughs]

BH: But you're not! You're not Irish to the core.

PM: I'm not and I actually a grew up right at the border during the Eighties, late Seventies, Eighties. You know… very strongly nationalistic fervor, very close to a place called Crossmaglen that got bombed every ten days or so. And that pushed me really back against you know, sort of nationalism and patriotism et cetera. So do I feel Irish? Well, I've got this accent, you know, it's part of my culture but so too is, you know, favorite writer is Douglas Adams, British. Favorite band is Rush, Canadian. Do I feel, you know, incredibly connected to Irish culture? You know, I love Thin Lizzy, an Irish band. I hate Uillean pipes and I hate Gaelic football and Gaelic sports [chuckles], so… yeah… it's… I've never felt particularly patriotic, I've got to admit.

BH: D'you know in all of the years I've known you, and all the conversations we've had, I guess we've never talked about this 'cause I always thought of you as a guy who was really like Irish and like, you know, felt like an Irishman in England and Up the English and stuff but you're like, no.

PM: Well, you know, there is that. You know, there is some aspect of that. I do remember some feedback from students, [laughs] one particular comment in the first set of lectures I gave and the module questionnaire had come back, how would you improve this lecture? How would you improve this lecture module? Make the lecturer less Irish. So [laughs] and also as we were just discussing before you started recording, Brady, the three thing. I got hit by that, the dirty

three and a third* thing over and over again [chuckles]. So the accent is part of me but, you know, do I feel very very Irish? [sighs] I feel more Irish than British certainly but… you know… I'm not particularly nationalistic or patriotic.

*[Ed note: In some accents the English Th is pronounced closer to a T, hence 'three and a third' may sound like 'tree and a turd.']

BH: What were you like as a kid? Were you nerdy, were you into maths and physics and…?

PM: Very nerdy. Hugely into science fiction, Star Trek, Star Wars, favorite comic was something called 2000 AD, which I hope some people still remember. Home of Judge Dredd. Uh… into astronomy, into NASA, I remember… I think I've told you this story before, Brady, but writing off to NASA round about the time the Voyager probes, when I was ten, in a ten year old's scrawl, and it's not much better now my writing, which was, Dear Sirs, I really enjoy the Voyager probe, could you please send me some photos. And sent it off and forgot all about it and then three months later in the heart of rural Ireland this big envelope full of... stuffed full of photos with a letter, to Mr. Moriarty, arrived and I said, oh wow! [chuckles] and so that was amazing, so thank you, Nasa. That was a big influence. In the end I didn't go down the sort of astronomy route. I went down the… got a microscope for Christmas at one point and that pushed me in the other direction. So smaller things rather than bigger things.

BH: So If I've gone to you as a little kid and said, Phillip, what do you want to be when you grow up? What would the answer have been?

PM: So it depends sort of what age but at age eight or nine, probably an astronaut. At anywhere from about eleven, ten or eleven onwards, probably a scientist. And even though I didn't really have a good conception of what that actually meant, scientist. Then further on when I found guitar, rock star, well that didn't work out [chuckles] and then back to being a scientist again [laughs],

yeah.

BH: [laughs] What were you like at mathematics? This is Numberphile so I always like to ask people about their relationship with mathematics.

PM: Okay, for a physicist this is a very guilty confession. I'm a really poor mathematician. I did not well in maths courses. I have to think really really hard. So I banged on in so many Sixty Symbols videos about my favorite aspect of maths which is Fourier Analysis and transforms and I love maths but I… it… in so far as anything comes naturally… it certainly doesn't come naturally to me. What does… what did come a lot more naturally was coding. And I spent a lot of time during my degree, my mantra was, can I code this? Because if I can't code this, in other words if I can't see an algorithm to translate the maths into something I put on a computer, I don't understand the maths, so that really really helped, so…

BH: Keeping you as a kid though, 'cause I wanna…

PM: Mhm.

BH: I wanna deal with you as a child first. I'm assuming 'cause your even a little… you're slightly older than me. I'm assuming there wasn't loads of coding at school for you?

PM: Yeah, so the very first computer I got was a ZX-81 in 1981. A Sinclair ZX-81. And that was one K of RAM and you talk about nerdy kid, so another really influential event was when I wrote some code for the ZX-81 and sent it off to a computing magazine and they published it and I got, I dunno, thirty… it was actually quite a lot of money for… I'm probably… it was probably two quid or something [laughs] but I remember it as thirty quid, like a big sum of money. When I was…

BH: What did you code? What was it then?

PM: So it was like a couple of games. A few games and it was a listing, so you'd type these in… into and it was… I just sent a listing and so it was like… a space game where basically you had a V. Like literally the character V.

BH: Yeah?

PM: And moving through a field of asteroids and the asteroids were asterisks and you had to dodge back and forth with the keys and just get through to the sort of boss thing at the end.

BH: Awesome.

PM: Which on one K was… now that was a challenge. A real challenge, coding anything in one K but it was so much fun. Yeah and that's really so that's… it was the combination of as we've discussed before in one of the Sixty Symbols videos, the whole radio thing and my uncle's a radio amateur and he and I played around with a lot of circuits and built crystal radios and stuff. Coupled with a couple of years later on… so '81, I was thirteen, and so yeah, so it was the combination of the always an in interests in circuits and electricity and then when computing came in I just got absolutely hooked on computing. Wrote the world's… no on the ZX-81, but on a ZX-Spectrum. Wrote the world's stupidest Pac-Man gave with the stupidest ghosts that just basically went to a corner and stopped.

BH: Was Pac-Man a V as well or…?

PM: No Pac-Man… this was a ZX-Spectrum so we actually had, I can't remember, sixteen colors or something, at that point two hundred and fifty-six colors possibly. No, it was… it was a little bit better than that, it was still pretty awful.

BH: We have to find that space game and resurrect it for Computerphile.

PM: That's a good idea, if we can find… I have no idea how to go about it. I can't even remember… I'll talk to my mum. She might well have kept it somewhere. Yeah she might have.

BH: [sighs] That would be amazing. Another story from your younger days that I always love hearing, I don't know… if we've told it on a podcast or in a video but about the… you and the communion wafer. This is shows that you were destined to be a scientist to me.

PM: [laughs] Yes. So I was brought up in an intensely Catholic environment. Mass many times a week, Catholic primary school, didn't see the outside of the church all of Easter. Just spend the time in there. And one of the classes we were discussing the wonderful aspect of Catholic doctrine known as transubstantiation, which is where the host in the communion, the piece of bread is meant to actually become the body of Christ. So I had… this was just after I'd got that microscope for Christmas, I dunno it was nine or ten, I can't quite remember. And I got very excited. Stuck my hand up in class said, oh, oh, oh! We can do this really great experiment. We can look at the host beforehand with the microscope, I've got a microscope! And then we can look at it after we do all the eucharist and the holy communion thing and then we can see the difference and we can see it converted from the bread into the body of Christ. And I got sent out of the class and I [chuckles] got sent to the priest for added instruction and got told those were not the type of questions you should ask. So me and religion started to part ways around about that point and time.

BH: I hope you remember that feeling next time I ask you a question during an interview and you say…

PM: [laughs] No, not goin' there! [laughs]

BH: I don't… [laughs]

PM: That's purely from ignorance, yes. [laughs]

BH: So as you got to the end of high school, you obviously had made firm decisions about what you wanna do at university. What did you choose to do at university?

PM: So physics, and I actually did an applied physics degree. I went to Dublin City University. I was not a great student, which possibly we can get to, but did applied physics and the reason I went there rather than other universities is that the open day was phenomenal and they had lots of, you know, fiber optics stuff and robotics and I was just in my element, loved it. And went there did reasonably well in first year, not so first in second year because the music thing was startin' to interfere with studies, and completely failed my third year.

BH: Completely failed?

PM: Mhm.

BH: So what did you do?

PM: Right, so I repeated my third year and I tell that story to tutees now, particularly tutees who've done poorly in exams and they feel that it's the end of the world. And I felt it was the end of the world at that point, but I know for a fact if I hadn't've failed those exams, I would not be here now. I would not be doing this job, because I was drifting really badly. If I'd managed to squeeze through third year without failing I'd have drifted through fourth year. There's no way I'd have got the marks I needed to do a PhD.

BH: What did you do wrong? Were you just going out and drinking and

playing in bands?

PM: So I don't drink alcohol. [laughs] So it wasn't that. It was the band thing. So the night that I remember vividly right before the maths exam, we played a gig in Donegal, and got back into the house… round about three o'clock in the morning, then got up to get a bus to Dublin at six o'clock in the morning, had three hours sleep. Didn't do so well in that exam. And that's… it was really that I was distracted with other things. Plus the fact I'm not a particularly good mathematician either, so.

BH: How important was mathematics through that University period? You were there to do physics… and you said maths, you know, wasn't your passion, what was that relationship like?

PM: Maths is the language of physics. So I just had to knuckle down and get there and first year I did a reasonably good job, and as I said it sort of faded off over the next few years. Fourth year I had to put an awful lot of effort in, but… it's a question of practice, it's like anything… if you know, I don't want bring up the tired musical instrument example that I use all the time but if you want to learn something you practice it and you practice it and you practice it up to the point where you know pain almost. And that's what it was like with maths. The way to learn maths, and the way to get any type of mild proficiency even with maths is to just keep doing problems.

BH: I talk to mathematicians more than physicists on this podcast, and you know, I'll hear them talk about they got to university and for the first time they understood the beauty of a proof and they saw maths in a new light and all these beauty. Do you have that kind of appreciation for mathematics or for you as a physicist is it just like a tool? Like a screwdriver?

PM: So for me the real beauty, I do have that appreciation. The things like, you know, the Mandelbrot Set for example, which is just amazing. This whole

mathematical universe. But where I really get excited is where you have the mathematical framework connecting different aspects of the universe around us. It's been described as the unreasonable effectiveness of maths in terms of describing the universe and that's where it really really hits me. Not so much in proof. There are no proofs in science. So we don't… and things that, you know, when we talk about D X DT, in terms of maths, when we talk about calculus. There are Ds in the real world. Everything's a delta. And so too often think that distinction between physics and mathematics is lost, you know, and sometimes you can get carried away with the beauty and the elegance of the maths, and sometimes that leads you in the right direction and sometimes it doesn't lead you in the right direction at all.

BH: Do you ever look at mathematics as a discipline, have an envy for that? Do you look at it and think oh that's beautiful and different and it hasn't got that kind of messiness and uncertainty that my experiment physics has? Or do you look at it with disdain and think…?

PM: No, there's beauty in the messiness. I'm an experimentalist. I am a dyed in the wool experimental physicist. And, you know, we collaborate with theorists, we even in dabble a little bit in theory ourselves, but there is nothing like, you know, when you get a new experimental result, something that possibly nobody else in the world or possibly nothing else in the universe has ever seen before. That's what really sort of gets me out of bed in the morning. And if that connects with theory and you can explain it, wonderful, but it's the discovery aspect, I guess. You know, the explanatory beauty of the mathematics is great, but again, you know, sometimes you can get caught up and you think, well this theory's got to be right because it's so elegant and so beautiful and I've… you know, I've been… disappointed so many times when you think, we've got it! We've got it! and then an extra piece of data comes in and… something that looked so seamless and so beautiful just comes crumbling down.

BH: But of course mathematics does have discovery and breakthroughs and

you know… and frontiers.

PM: It does, of course it does, and… you know proofs are important [chuckles], I'm not saying proofs aren't important. You know, anti-matter for example and positrons just popped out effectively of solutions of the equations and you know mathematics makes predictions and physical theory's based on that mathematics predictions but they are predictions and they remain predictions until we can actually get the experimental evidence to support them. And increasingly, in some aspects of physics that will remain nameless, that link between experiment and theory, it sometimes felt that well, you know, as long as the maths is self consistent and as long as the maths is elegant then that's all we need and as experimentalist no… I can't take that. [laughs]

[gentle chimes]

BH: Just a quick interlude to thank today's episode sponsor G-Research. This is a world leading quantitive finance research firm based in Europe. G-Research is always looking to hire the brightest people to tackle the big questions in finance and applying all the latest in machine learning and big data, all that cutting edge stuff. If you're good with numbers or mathematics or computers, well, this could be your big chance. G-Research is really focused on creating a great work culture and nurturing future talent. If you'd like to find out more about them and the opportunities there, go to gresearch.co.uk/numerphile. That's G-Research, create today, predict tomorrow.

[gentle chimes]

BH: Going back to university then, after you kinda righted the ship and redid your third year and…

PM: Mhm.

BH: And got through it, at what point did you start seeing a specialization and where your career was gonna go?

PM: So actually, I was planning on going into sound engineering at the end of my fourth year, as you might have guessed. That's really where I've… I've always been interested in music and I'm interested in you know signal analysis and waveforms and hence Fourier Analysis et cetera. What made the difference is that along with the graduation letter there was a letter sent out round about June advertising a PhD, now somebody had been identified for that PhD but they dropped out at the last minute and they were contacting all the final year students, and it was on STM, scanning tunneling microscopy. And I was aware of work that had been published very very recently, it was the first time atoms had been moved around and to spell out a word, IBM. When I got this letter and I knew it was about STM, I got back in touch very very quickly and said what was the possibility of actually getting involved with that project and didn't look back. Within six months of starting that I… sort of knew that I wanted to be an academic.

BH: So this sounds quite serendipitous, like you just kind of almost like… convenient. Did you just do it out of convenience, 'cause you wanted a job and an option or did you see something in STM that made you think, I love it! This is where I want to be.

PM: Oh! It was the latter. It was the latter, definitely. It was wow, I hadn't even really considered doing a PhD, it was the subject matter and the fact that… didn't start off like this but ultimately it was about using an STM to manipulate atoms which, you know, given all the way back to when I got that microscope as a kid that was perfect for me.

BH: Can you tell us what scanning tunneling microscoping all about? What's goin on here?

PM: Yeah! I can. It's a microscope like no other. There are no optics, there are no lenses, there are no mirrors. And conceptually it's actually easier, I think, than… easier to understand than a traditional microscope. It's basically a record player. It's like an old style record player. You've got a stylus, except in this case that stylus is atomically sharp, and you move it back and forth across a surface and you use that to map out the features of the surface. That's it in a nutshell. Now the tunneling bit comes from quantum tunneling. The tip isn't actually in contact, though we can do that as well, with a surface and there's a current that flows which is due to quantum mechanics and you measure and map that and use that to map out the surface right down to the atomic level.

BH: So that's sort of almost like having your eyes closed and just rubbing your figures over something…

PM: Mhm.

BH: …to feel what's there.

PM: That's exactly it. And in fact there's scanning tunneling microscopy but there's also it's counterpart which we do more of now, I would say, which is atomic force microscopy which is exactly that. You're mapping out the forces.

BH: What's the advantage of this kind of microscopy over… optical stuff and electron microscopes and things we will have been more familiar with?

PM: The great advantage of the scan tunneling microscope is the resolution. The resolution is right down to the single atom level. Now you can achieve that with electron microscopes. What you can't do easily with electron microscopes is actually push those atoms around. So the scanning tunneling microscope… atomic force microscope, they're called scanning probe microscopes as a family of techniques. You can… manipulate individual atoms and actually this state of the art isn't even atomic resolution, it's down at the single chemical bond

resolution. In terms of an optical microscope you just can't get down to that type of resolution because the wavelength of light is too large.

BH: Why do you wanna be moving things around?

PM: Oh, so it the way I sometimes in inverted commas sell this, is wouldn't it be neat to do 3D printing with atoms? Wouldn't it be neat to have like a Star Trek replicator? Where you could dial in a blueprint to make something and then have it constructed from the very atoms sort of all the way up? And we're a long long long way from that but it is ultimately the… the ultimate limit of 3D printing is the individual atoms.

BH: So it's called microscopy and I always associate that with looking at things but this field isn't just about looking at stuff, it's about like building then?

PM: Precisely, yeah. So you can just use it to look at stuff, but you can also use it as a tool and in fact the great thing is all you need to do to switch between those two modes, it's the same instrument, is move the tip a little bit closer. So when you're imaging you pull the tip back a little bit further from the surface, so you don't disturb the surface. If you want to move atoms around, push them, pull them, pick them up, put them down, poke them, then you just move the tip in.

BH: I've seen some of the machinery in your lab and I've also heard you tell stories and [chuckles] seen you curse and swear at the difficulties that you might have, it's a fiddly thing isn't it? Like it's a bit of an art-form?

PM: So I've just spent the last… that's a very timely question, Brady. [chuckles] I've spent the last two weeks on my back underneath what's called an ion pump, one of my colleagues said, it sounds like something Han Solo would say, I only wish it was as exciting as the Millennium Falcon. So… trying to fix things, getting ultrahigh vacuum can be a real challenge, so, I haven't even

explained why we need ultrahigh vacuum. So we're looking at surfaces, we're manipulating atoms, what we don't want is a lot of contamination. And atmosphere is a big contaminant. So we have our microscope in what's called an ultrahigh vacuum chamber. Pressure in there on a good day is comparable to that you get on the surface of the moon in terms of the level of contaminants and… getting that vacuum and keeping that vacuum [sighs] can be frustrating.

BH: But also the tips themselve, I imagine they're… are they fragile things these little pointy tips that are scrapping over the surface?

PM: That's a very good point as well. Yeah the tips are… difficult to create sometimes and difficult to maintain. In fact a major program of work we have at the moment is using machine learning to try and train the instrument to keep the tip in the best possible state. So at the moment the way it works is. You take a piece of wire, you etch that wire, you put it inside, you scan, most of the time you're not gonna see atoms, 'cause just the tips too… it's not in a good state. So what do you do then? Well, you sort of tickle the tip with little voltage pulses. You increase the current. You push it into the surface a little bit. You push it into the surface even more. You wiggle it round. Anything to get atomic resolution.

BH: So you're just trying to mash it into a lucky shape?

PM: Basically you're mashing the rocks together, yeah. And hoping that in the end you're gonna get out atomic resolution. Now once you've got that atomic resolution you can do very sophisticated things like pick up molecules and use those to control the tip. But again that molecule can drop off and, you know, the tip can change spontaneously or not so spontaneously and so at the moment what happens is somewhere between thirty and fifty percent of a researcher's job is getting that tip in a good state. So, there's no reason why a researcher should be doing that, hence machine learning.

BH: In your research and your experimental work, rather than your teaching.

What mathematics do you use, on a day to day basis? What do you need to do?

PM: Oh, okay, so… that's a… very good question. So we… so as I said we're experimentalists so we take that data off, we are fitting that data and we're comparing it largely to something called density functional theory. But that's very computational. In terms of pen and paper maths… in terms of research… I don't do that. It's not something I do. So there are, you know, we may tweak codes, we'll, you know, Markov chains and Monte Carlo methods, we'll use those but not in terms of pen and paper maths. It's all… it's actually all computing based.

BH: You never sit down and have to use calculus.

PM: Uh… in my teaching yes.

BH: Right.

PM: And now isn't that interesting? That there's a rather big divide between what I actually do on a day to day basis and what actually we teach. And for me, I will say it again and… I did have a quantum course just last semester… for me computing is at least as important as mathematics, if it were up to me, I would have computing dominating over the maths, in physics courses. I know… I can hear my theorists friends screaming in anguish, not to do that, but… for me, I think that the one issue with purely analytical maths is that we lose that messiness, which is a feature of the world around us, so knowing that we have noise. Knowing that we don't have infinite resolution, we have deltas rather than Ds, is very very important, and we lose that sometimes.

BH: So until quite recently, I know you were the admissions tutor here at the University of Nottingham. [laughs]

PM: Mhm.

BH: I wish you could see the look on Phil's face then, it obviously wasn't the easiest job he's ever done. If someone's listening to this an thinking, oh, Phil Moriarty, he's got a cool job, that's a cool life, I'd like to do that, and they're still say at school.

PM: Mhm.

BH: What would you say to them? How can they get into this kind of world?

PM: So… the route, the traditional route and well I'll tell you my route, and my route in was I was not a very good student, that's the first thing. I failed those exams and I'm not suggesting that failing exams [chuckles] is a good life choice. But then I did a PhD, in my case the PhD took a little over three years. Duration of PhDs can be anywhere from, at least in the UK, from about three to five years. In the US and elsewhere, in Europe, it can be a lot longer than that, so it depends. Then I did a period of Postdoctoral research, which is after PhD, which in my case was three years and then I got a lectureship, so that's the traditional route in. It doesn't always have to be like that but the traditional route is, high school, physics, maths, et cetera, undergraduate degree, PhD, some people then do a Masters between the undergraduate degree and the PhD, and then periods of Post Doctoral research.

BH: What kind of decisions can they be making now, though, to ease the path?

PM: So if they want, if they're interest in doing physics or I guess for to Numberphile audience in terms of doing maths, they really… and if, well depending on what level they are it's a question of GCSE and A level choices. They need to be doing the right subjects to ensure… now it's not the end of the world if, you know, they've… they don't do the right subjects and then say five or six years down the lines they decide they want to go into maths. There are

foundation years, there are, for example, Open University, there are other ways back in but in terms of the traditional route, make good decision. Talk to universities about… and talk to admission tutors. Come to… I know we can't have Open Days right at the moment but hopefully they'll come soon. Talk to the admission tutors and get good advice about what subjects they should be doing.

[chimes ring]

BH: A lot of the people listening to this will know you because you've appeared in Numberphile videos, you've also appeared in lots and lots of the Sixty Symbols videos about physics that I've made with you. Even Computerphile, I know you're in loads of those videos, so what's it like being a popularizer of science on the internet?

PM: [laughs] It has it's good sides and it has it's downsides. No, it's amazing, so I've had… I think I've forwarded that email and I told him so that… that guy that got in touch who as an undergraduate actually just starting his first year and in high school got in touch… N years ago, something like eight, maybe nine years ago. Got in touch, said that Sixty Symbols, you know, had inspired him and he wasn't thinking about doing physics and then he ended up doing physics and I've been in… I've kept in contact with him and he sent me an email just a few weeks ago and now he's done a PhD and he's thinking about goin' on to do Postdoctoral stuff. It's just amazing to think that you have that type of influence and I'm not talking about me personally, I'm talking about the entire channel. That's an amazing part of it. The other side of it is… those random emails you get from people who've decided they… they and they alone know the secrets of the universe and they're gonna tell you about them at interminable length [laughs]. But I think we both experience that. But it's… it's fun I enjoy the teaching side of things, as much as the research and I've said this to you before, Brady. You have completely changed the way I teach. The way you ask questions, the way you keep me on my toes, [chuckles] the way you have changed… just the way I explain things through this. So this Sixty Symbols has fed directly into

my teachin' and of course into the research as well in terms of when I now go and do presentations, keeping in mind your journalistic approach to thing, I think is… sometimes creates tension between us but that tension's a good tension.

BH: Aww, you often say… like Phil and I before we do any recording have some very passionate discussions. Not arguing but just like really passionate.

PM: Sometimes arguing. [laughs]

BH: Sometimes arguing. But as friends. But many times Phil says, you should be recording this! This is great! But I'm not sure people are ready for that.

PM: [chuckles]

BH: But that does lead me to say, you know, you are so passionate and you're like, you know… uh… in a good way quite a volatile personality.

PM: Mhm.

BH: How as that tied in with things like social media and comment sections on videos and that? That's not always been a made match in heaven, has it?

PM: No it hasn't and I've… for example you warned me, don't go anywhere Twitter, Phil. Don't do Twitter. Don't do Twitter. And then I did Twitter and then I came off Twitter about eighteen months later, bad idea. I do not have the temperament, [chuckles] I'm rather too argumentative for that. The comment sections are [sighs] interesting, you know, the conventional advice is and… colleagues and… students in the group and researchers in the group will say that, you know, comment section of Youtube is just basically the entire condensed collective stupidity of humanity in one easy to locate place [sighs] and sometimes that's the case but on the other hand some of those comments have actually again

fed into research and teaching, and… they can be frustrating and they can be a good thing. You know, we did this video on the Heisenberg Uncertainty Principle, I was at pains to say, oh it's not a measurement problem and the first bloody comment that ends up with six hundred upvotes or something is, well this is this! And you realize that actually it's… it's not just a question of putting out the right information. It's a question of, you know, people have biases, people have ideologies, you know you can have water tight arguments in terms of the science and you've seen this in terms of disinformation and misinformation right across the web, countering that is not just a question of the science… it's a question of how you couch it. You say, no who have they gone to listen? Who is somebody who doesn't, you know, doesn't take the evidence for Climate Change seriously? Are they gonna believe me a lefty academic? You have to find someway to nudge them in the right direction and me shouting at them or others like me shouting at them is not gonna do it. So… social media I had my fill of, I got to admit, and I pulled back from social media a number of years ago and I don't regret coming off Twitter one little bit.

BH: Let me give you a few free swings at some popular issues, that I know over the… some of them I think you may have opinions of, some you may not, I don't know but… but let me hear what you've got to say about them. Funding of blue-sky type science, versus practical science that's gonna make better iPhones, 'cause this was something when I first met you, you always seemed to be banging the drum about and arguing with people and putting your foot in it and I don't hear you talk about it, maybe 'cause your off social media, but like, how are you feeling about how that's going these days?

PM: There is a part in terms of social media. It's… yeah, there's again it's there was an article in the Guardian just a couple of days ago about this issue in terms of blue-skies research and funding for research. It's a perennial issue. You know the division between what we call blue-skies research, which means funding for research that doesn't have a tangible near term benefit versus stuff that will generate a product, stuff that will generate, you know a device or an impact, a

real world impact. The true answer is somewhere between those two extremes. Actually for mathematicians it's even more important because, you know, mathematicians, an awful lot of their work is very very fundamental, you know, with like complex numbers… quantum mechanics… you know, it's absolutely key, nobody knew in terms of hundreds of years ago and how important complex numbers were gonna be for quantum mechanics and quantum cryptography, et cetera. And there are countless examples, the laser's another one that's brought up with great regularity in that the guy who… Townes, the guy that developed the laser, his head of department start playing with this, it's only every gonna be a physicist toy and look where lasers are now, so… you can't predict but on the other hand, it's taxpayers money and it's… it's not sometimes the most powerful argument, well just give us two hundred years and something may eventually come out of this. And there's a question of how do you divide that money and how do you put it into the work that is gonna have both an academic impact, push the field forward, and impact that has some return for the taxpayer. For me? I would say that the govern… you know, it's a fairly simple argument. I would say if it's close to market, let the market fund it, you know, if it's… governments should not be in the business of, you know, doing Toshiba's funding… academics to do Toshiba's work for them, effectively. If it's close to market, let the market fund it. The universities should really be about, you know, the more fundamental side of that equation.

BH: You're reasonable well funded, [chuckles] I mean…

PM: Mhm.

BH: You're managing to keep your group going and your quite blue-sky, so you know…

PM: Mhm.

BH: Um.

PM: No that's right, no that's an important point, Brady. You know, I've criticized the research councils quite a bit over the years but you're absolutely right, the stuff that we do is pretty blue-skies… and…

BH: Do you think they've got the balance right at the moment or is the balance tilted to far to industry?

PM: We're in a bit of a state of flux, not least in terms of Brexit and stuff and it's not just the research councils in the UK, it's the broader picture including things like the European Research Council that need to be taken into account. But… [sighs] it's the… I think the balance is about… I hesitate to say this… compared to where we were ten years ago when I was mouthin' off all the time, the thing that really frustrated me back then was there was a very strong push in terms of commercialization and making sure that your work had commercial impact. And everything, all the messages were coming out about real world impact but real world impact not in terms of what you do… in terms of Sixty Symbols which is real world impact as well and… Numberphile, et cetera. And public engagement. But very much pushing towards the commercialization side of things. That's been rolled back over the years. So I'm… I'm a little less grumpy. I'm also ten years old so that probably… [chuckles]

BH: Another thing that academics often get grumpy about is the way that publication works in science.

PM: Mhm.

BH: And… or the way the money works and you have to pay to get things published.

PM: Mhm.

BH: And then pay for access to journals and that… is that… are you relaxed about that these days?

PM: I'm not. I'm… less relaxed about that. The real… they're a so many issues about that and we could have a whole series of bloody podcasts about that, Brady, but, one of the issues… I'll give you an example. I work in nanotechnology, so we have a wonderful journal called the Beilstein Journal of Nanotechnology, which does everything we could ever expect to hope of… a journal in that its entirely free to publish and it's entirely free to read. The Beilstein Foundation in Germany has immensely deep pockets that allow this to happen. Why don't we publish all our work there? The reason we don't publish all our work there is that the entire scientific reward system in terms of careers is effectively based on the brandname of the journals in which we publish. In that if you publish in the Beilstein Journal versus if you publish in Nature or Science, you're gonna… make it… you're career's gonna be a hell of a lot easier to develop than for the Beilstein Journal. I am a hypocrite, in that I think we should be published in the Beilstein but if I did that and I said, right, we're only ever gonna publish in the Beilstein Journal, if I said that to the researchers in the group I might as well say, you're not gonna have a career. So we have to go for those brandname journals as well.

BH: Is that… is it exactly quantified. Is it like eight points for a article in Nature and two points for an article in Bilestein or is it more… kind of subtle and reputational than that.

PM: It's more subtle and reputation… in fact there's something called DORA which is… oh I've forgotten what it stands for, Declaration of Research something, I can't remember what the A stands for. But it's something that an awful lot of universities and publishers have signed up to, which is where you don't use something called the Impact Factor, which is based on the number of citations the average paper gets in a certain number of years for a journal. And you shouldn't be using things like Impact Factors, there's also something called

H-Index, which relates to the number of citations given. And it's more about looking at the overall quality of the work. But that's very subtle and I've been… in many situations where… the CVs for researchers, postdoctoral researchers or even a lecturer level and people around the table are looking at these and one person will say well Candidate A has got better publications than Candidate B, and this is the key point, Brady, without ever reading those publications.

BH: Ah.

PM: The decision is made in basis of the brandname.

BH: Let me poke you with one more stick.

PM: [laughs]

BH: League tables.

PM: Ah hah hah! [laughs] Okay.

BH: Tell people what a league table is.

PM: Oh, okay. So league tables are… in a range of different… in particular with regard to, you said Brady, I was an admission tutor. So there are university league tables, and those universities league tables are published by newspapers and by magazines like the Times Higher Education and they have a dramatic influence on the applications for universities. And the problem with them is that they are pseudo-statistical at best and complete and utter… nonsense. [laughs] I'm not allowed to swear, Brady, am I? Nonsense at worst. I was struggling to…

BH: [laughs]

PM: …restrain a word beginning with B there. And… the problem is that they

are… utter nonsense so I used to try and get this message across all the time to applicants and their parents for… when they came for open days to… or courses. And parents would say, well you know you've slipped so far in the league table. It's nonsense, we went from eighteen one year… in one particular league table to five. What did we do different? We did absolutely nothing different. They changed the… sort of metrics by which they set the league table up. Moreover, you know, departments rise and fall on a year by year basis and it sells papers. It sells magazines. But they are nonsense. If you asked have I sort of mellowed on certain things? I've not mellowed on that. I will never mellow on that. And what really irritates me is when physicists who should know better and mathematicians who should know better take those bloody league tables seriously.

BH: So they're put to… you think you would argue they're put together quite arbitrarily using… unfair metrics?

PM: The… those who put them together would argue otherwise. I would say that the metrics it's… how does the quote go? Many things that count cannot be counted. The question is, it's very difficult to quantify so any aspects of a department and then to crystalize that down into a single number? It's ridiculous. We're not football teams. [stutters] A physics department, a maths department is not a football team and which rises in the table depending on… you know… performance. Doesn't go like that.

BH: Alright. Can I ask you a question that's gonna make you hate me even more than all of this stuff?

[pause]

BH: Are you ready?

PM: Mhm.

BH: Deserted island discs. What five albums will you take with you to an island?

PM: [chuckles]

BH: And you have to answer now without thinking time.

PM: Oh my god.

BH: Five albums.

PM: Five albums. Okay. Rush's Moving Pictures. That's absolutely top. Jellyfish's Bellybutton. King's X's Out of the Silent Planet. Metallica's Master of Puppets. Uh [hesitates for time] and probably a Kybosh album… um… maybe… um… so many others that's really tricky. Maybe an Opeth album. Okay I'll go for Opeth's Ghost Reveries which is about as far removed from Kybosh as you can get. [laughs]

BH: Would you…

PM: Damn you, Brady.

BH: Would you give up your physics career, expunge every paper you've ever written from the records and go back in time if it meant you could be… a music star?

PM: Oh, what a… feckin' question. Wow. [pause] No. I don't think I would. [pause] I don't think I would, 'cause that means givin' up sort of my life to this point. [pause] Yeah.

BH: Yeah.

PM: No. No. There are many other aspects, you know I enjoy this job, et cetera, but there are many other aspects of my life to this point, you know, I'm not saying I don't have regrets, of course I have regrets, but you know, [gentle music fades in] there are many good things that I would not want to lose.

[piano music gets louder]

BH: Our thanks to Professor Moriarty for being on today's show. I'll include some useful links to Phil's work, his writings, and some videos in the notes for this episode. [piano music continues] Also thanks to G-Research for their support and the Mathematical Sciences Research Institute in Berkeley, California. [music continues] Again, see the notes for some useful links. I'm Brady Haran, and you've been listening to the Numberphile podcast.

[Music fades up and out]