Discussions

Volume 17 | Issue 2 Article 1

Faculty Spotlight: Dr. Harsh Mathur

Jonathan Wilcutt
Case Western Reserve University

Recommended Citation

Wilcutt, Jonathan () "Faculty Spotlight: Dr. Harsh Mathur," *Discussions*: Vol. 17: Iss. 2, Article 1.
DOI: https://doi.org/10.28953/2997-2582.1178
Available at: https://commons.case.edu/discussions/vol17/iss2/1

AN INTERVIEW WITH

Dr. Harsh Mathur

By Jonathan Wilcutt

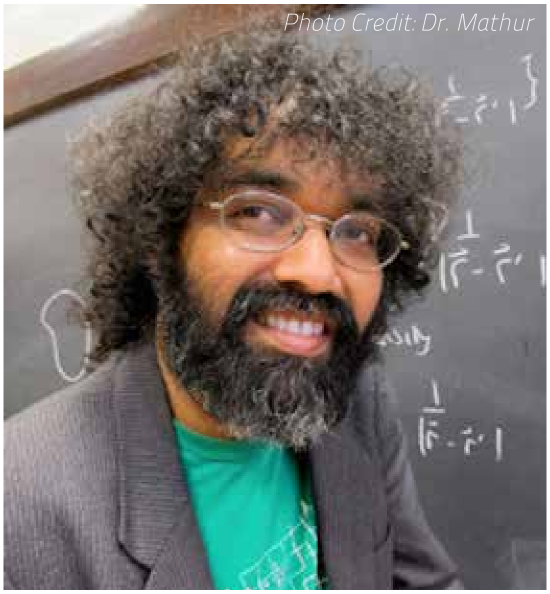

Photo Credit: Dr. Mathur

A Selection of Dr. Mathur's Work

Mathur, H., Brown, K., & Lowenstein, A. (2017). An analysis of the LIGO discovery based on introductory physics. *American Journal of Physics*, 85(9), 676–682. https://doi.org/10.1119/1.4985727

Jones-Smith, K., & Mathur, H. (2006). Revisiting Pollock's drip paintings. *Nature*, 444(7119), E9–E10. https://doi.org/10.1038/nature05398

Dr. Harsh Mathur is a Professor in the Case Western Reserve University Physics Department. His current research interests include condensed matter theory, theoretical particle astrophysics, and cosmology. Dr. Mathur received his Ph.D. from Yale University. In this interview, he discusses his journey in the field of physics and the lessons he learned along the way.

This interview has been edited for length and clarity with Dr. Mathur's consent.

Q: What brought you to physics? How did someone with such broad interests settle into just one field?

A: What brought me into physics was astronomy initially. I realized that if I'm going to work in astronomy, I need to understand physics and math. And then once I got into physics, I discovered quantum physics and thought that was the coolest thing in the world. Quantum mechanics is buried deeply into subatomic structures.

Typically, we don't see quantum phenomena in everyday life. You and I are sitting here, and it's a very ordinary world. But deep down inside, the world is very strange. In condensed matter physics, we can access that strangeness, and it determines the properties of materials. This was absolutely fascinating, but I did have my interest in astronomy, fundamental physics, elementary particle physics, and cosmology lurking in the background. I joined the faculty here in 1995. I was doing quantum condensed matter physics until around the 2000's, but then I got diverted into doing some other things because I shared the corridor.

> "Once you start working with young people, you have to make more of a commitment...You have to become a card-carrying member of the community so that you can support their careers..."

My office is right next to the cosmologists, and we were always talking. Sometimes we would get into quite deep conversations. Whether you are doing quantum condensed matter physics or cosmology, many of the tools of science are more or less the same. But it was just the sort of thing we talked about over coffee, and then I would go back to my life and they would go back to theirs. But at some point, I wound up working with a postdoc and a student in their group whose advisor I became eventually. Once you start working with young people, you have to make more of a commitment. You can't just have an interesting conversation and leave it there. You publish papers. You have to become a card-carrying member of the community so that you can support their careers and so on.

It became real because I started working with the Postdoc and the student, and there's a bit of a story there–I actually migrated into cosmology by way of art history. We have the pizza seminar on Fridays where each week people get together–the students, the faculty, the postdocs–and alphabetically, more or less, people get to speak. That's the price you pay for the pizza. Usually people talk about their own research, cosmology, or some interesting new paper that they read on the arXiv so we can all stay up to date on interesting things that are happening in the field.

My student, Kate Brown, decided when it was her turn, she'd heard far too many talks about the cosmic microwave background and it might be fun to do something else. So she went scouting around and she found a Nature article that claimed that the paintings of Jackson Pollock were fractal and that you could use fractal analysis to tell if they were authentic. So she decided that would be a fun thing to present.

But in the course of preparing the presentation, she realized it didn't make any sense at all. She instead presented a really hilarious critique of the paper. I was quite impressed because Nature is a prestigious journal, and for a beginning graduate student to have the confidence to decide something in the journal is wrong and then put up really good reasons why impressed me. I and other people told her that she should write it up. She didn't because students never do what you tell them. She thought that she had to work in cosmology and be writing papers in that area if she was to have any future in this field.

But then six months later, there was front page news in The New York Times that a cache of paintings had been found that belonged to a guy named Alex Matter. His parents were friends of Pollock. Matter found these 25 paintings in his basement with a note from his dad saying the paintings were by Pollock. The art history world got divided about it, whether they were really by Pollock or not, or whether they were just student paintings of some sort. Scientists claimed that they had done fractal analysis and demonstrated these things weren't Pollock.

At that point, Kate agreed that we did need to write a paper debunking it. My favorite part of the paper was when she performed fractal analysis on this really childish drawing of stars that she made. According to the test from the paper, it was an authentic Pollock. This got to be a big media story. It got into hundreds of newspapers around the world. What we used to tell the newspapers was that, "either their test is wrong or our drawing is worth $140,000,000, and we're happy with either outcome." It wound up being in a textbook on chaos theory, the New York Times, and Nature. Not so bad for a student's first project.

Q: Already you've mentioned that some of your biggest career moments have happened because of coffee and conversations. How do connections with the community drive innovation?

A: Physics as a whole is a very collaborative field. It is not the case that you just sit in some dungeon by yourself doing some calculations, although there are times when you have to hide away and do that, but a lot of it is collaborative and discussion based. The best ideas come that way. Whole programs get created that way. My story is actually very typical for people like me who do theoretical physics and mathematical physics, mostly pencil and paper calculations.

Q: How big of a separation in Physics and other quantitative fields is there between computer simulations, analytical results, and experimentation? How intertwined are these all?

A: We only do simple computations on our computers and the rest by hand. The philosophy here is one described by a great mathematical physicist Eugene Wigner. Winger used to say if someone did purely computer analysis that, "I'm glad your computer understands the problem, but I would like to understand it too." I think that's an old-fashioned attitude that we have to shed. To refer to today's Nobel Prize [in climate models and spin glass], I think advances in climate science would not be possible without computers. It's simply not possible to work these things out by hand. But I think all of these things are complimentary. Computers haven't displaced the need for traditional pencil and paper methods, but rather they've augmented it in a very powerful way. Even the purest of pencil and paper theorists can't avoid some computing, but basically if I can't run it on my Macbook, I don't do those problems. Experimentalists and those who do supercomputer calculations take collaboration to another level. The people who study how protons are glued together are hundreds of people working together. You work on your little bit of code and you don't actually have a picture of the whole thing. No one person could write that whole code to do that. They have to be huge teams. In experimental science even more so. "Every paper is written by a thousand people," so physics is very collaborative. In terms of the connections between all of these things, I think there's a tremendous synergy between them. Without experimentation there is nothing, because we're trying to understand reality; otherwise, this would just be math. They are absolutely the backbone of our field.

Q: That brings up the question. Oftentimes, the math of the theories reveals counterintuitive, weird quirks of nature. As a theoretician, do you trust what the math says or do you just fall back and wait for experimental results?

A: You do wait for experimental results, of course. I don't believe anything unless it's consistent with experimentation. But experimentation doesn't make it seem more reasonable. All of quantum physics was built out of experimentation, but experiments are very indirect. If you think about how we learned about quantum phenomena, they were just measuring the spectrum of different gasses. They would just heat them up and then look at the light and pass it through a prism. They weren't really accessing the strange underlying reality; they were just observing stuff and then it was the theoreticians who wrote down equations to predict those spectral lines. And in the process of trying to understand those equations, they arrived at this bizarre interpretation.

Should you believe this bizarre interpretation? In the process, everyone has heard of this bizarre interpretation of Schrodinger's cat, that he might be dead and alive. Schrodinger didn't believe that, so once he wrote down the equation and realized this was the most natural interpretation of these equations, he said, "I am sorry I had anything to do with it," and he really did exit the field right there. He never wrote another paper on quantum physics again. Einstein didn't believe in it either, and he spent the rest of his life writing very incisive and insightful critiques of quantum physics. So thanks to Einstein and other people, they eventually came up with experiments where you could really test whether these things such as Schrodinger's cat and entanglement could actually be tested. In some sense, it's not really proper to believe in quantum mechanics. It was proper to be skeptical until those tests were done and they have been done now. There is this back and forth between the experiments and the theory. Neither would be complete without the other. Experiments would just be a bunch of speculation without the theory, but the theory is unbelievable until it makes predictions that let you say that this strange stuff is really true.

Q: What's the difference between continuous and discrete in physics? Are those both simplifications or is one correct and the other is wrong?

A: That's a very deep question. We don't know. But the shallower answer is that the world does seem continuous. The space around us seems continuous and time doesn't seem to go around jerkily. You have clocks where the hand jerks around every second and it jerks forward but this isn't our perception of time. Like we were in that moment and then suddenly we're in the next moment and so on.

Many things seem continuous, but then they are not necessarily. Like we know this table, which feels nice and solid and continuous, is really made of individual atoms. And these atoms aren't really like individual billiard balls, but they are these puffy clouds of quantum stuff. The solidity and continuity of things which is apparently there isn't really there.

What we have is a moving target. We don't have a theory of everything and I don't expect we ever will. So it's just what is our best understanding of what the universe is today. And in our best understanding of the universe today, which is called the standard model plus Einstein's Theory of General Relativity. Our best understanding of reality is that space and time are truly continuous, but of course things like solid objects that seem continuous are not. So that is what we know about reality but someday we might find that space is not what it seems. In fact, almost certainly it is not what it seems.

The weird thing is that what we perceive emerges from the much stranger underlying reality. So I expect that some day we will have some new insights into what space and time are, but in the meantime, it is a practical thing that sometimes it is more helpful to use a continuous model. As an engineer or as a 19th century physicist, if you're interested in the flow of fluids, you'd just write down these equations, called the Navier Stokes Equations, that treat fluids as a continuous thing. You're treating everything—space, time, a fluid—as continuous. In the 19th century they actually didn't know for sure if fluid was continuous or not. Now we know that it's actually just an approximation, but it's a good one. Conversely, at other times it's good to discretize things. So even space and time are sometimes convenient to treat as discrete because that makes it easier to put it on a computer.

Q: Do you believe that the discrete approach has gained more prominence in the past couple decades because it is easier to compute?

A: Well, yes and no. Yes, computers have become much more prevalent, and the need to discretize equations has emerged. If you want to solve the fluid mechanics problem, you might want to discretize space and time and then have discrete equations to deal with. But Newton did that. He was trying to analyze waves and didn't actually know how to solve partial differential equations, but he did know how to solve differential equations, so he discretized space and time. He made a huge system of differential equations. He modeled waves as systems of balls connected with springs. So this idea has occurred to people before.

But of course it was better to invent partial differential equations and subsequent to Newton, people did that. But now on a computer we do find it useful to discretize. There are some interesting, unexpected problems that come up in the process. It turns out when you try to write the quantum mechanics of quarks in a discrete space time, you actually can't. You would think you could write down some discrete version of the continuum theory. And somehow they could emerge from each other, just like you can discretize fluid mechanics and how continuum fluid mechanics is just the continuum limit of the discrete theory. But you can't do that with Quantum field theory. The reason they can't calculate this is that the quantum lattices have an extra copy of every particle. So they have to deal with that and make these extra copies and eliminate them when they try to connect to experiments.

Q: What is the most challenging part of being a researcher? Is it believing what you are saying is true sometimes?

A: No, I think we are quite good at believing things that are counterintuitive. And how are we able to do that? Sometimes you trip up because your instincts and intuition are not in accord with reality. But mostly, math is the crutch. So the reason I have any intuition about the classical world, not the quantum world, is because we live in it. For some reason when you deal with macroscopic systems, the quantum phenomena have all disappeared and we live in the world of everyday common sense—classical physics. I have a good intuition about that, although, even in the classical world, our intuition isn't always perfect and there are non-intuitive things about Newton's Laws or Maxwell's equations.

Maxwell's equations are pretty bizarre. This whole thing about invisible fields that surround us, it sounds like something like the Force from Star Wars, except it's reality! There really are these invisible force fields. I think even common sense classical physics is somewhat counterintuitive.

And the way we cope with that is ultimately we don't rely on our intuition, but we rely on solving a lot of problems like our homework problems. You develop some intuition about what electrical fields will do even though you can't see them. And you develop some intuition about what mechanical systems will do. I guess you could get that out of experience, but you also get that out of solving a lot of physics problems.That's how we build our intuition for the quantum world. If we come up with an outlandish theory that isn't standard, we are accustomed by now to build our intuition not by experience, but by math.

Q: To pivot, you mentioned your fractal analysis of art. You've also done statistical language processing, epidemiology, and work in plenty of other fields that are not the staple domains of physics. What made those problems attractive to you?

A: The Pollock project first demonstrated that it was possible to do this. We wrote a paper that generated quite a bit of interest, and I felt like we made a real contribution to the field. Those paintings may or may not have been authentic, but we were able to show that fractal analysis wasn't relevant. And in that way we were able to further the discussion around those paintings. I think it was the realization that you can contribute outside of physics that was kind of exciting. I was always interested in doing that, so that gave us the permission to keep doing that.

Q: What are your steps when you are researching a problem? How long do you spend reading the textbooks versus working on your model, etc?

A: Especially if you are doing work outside of your field, there is a learning overhead. If you're going to work outside of your field, it's good to talk to the experts in the field, but you also have to become an expert yourself. You can't outsource this work. In interdisciplinary research, you have to spend a lot of time learning stuff, but it's also an easy form of avoidance. It's so easy to read textbooks and do textbook problems. You can avoid the really hard part of just sitting down with a blank piece of paper and confronting something no one knows the answer to and shaping the question. It's not even a well defined question. It's such a hard thing and learning can sometimes be such a great way to avoid it and still feel like you're working on the project. It's a balancing act. I've got these two really fat books on Solar System dynamics with enticing titles such as Solar System Dynamics that have pictures of Saturn's rings, and people have tried to understand why there are gaps in them, why they have the gaps they do, and why they have these radially pointing spokes as well. So I wish I could just take a holiday and read them cover to cover. But we have to draw the line because we also want to and have to worry about other people jumping in who are experts in this field, maybe teaming up with experts in the other field we are bringing here.

> "It's hard to believe that you can do the things that you want. But it turns out you can if you go for it, so I think you should."

Q: Does it always feel like a mad dash when you are doing research to just get it out?

A: It can sometimes feel like a mad dash. When I was in condensed matter physics, I used to work on a lot of these mad dash problems and I've tried to move away from that as I've gotten older. But the maddest dash I've ever done, that in retrospect seems to have been a mistake, was in 2014. It was this long awaited thing that people really dream about. We have this creation myth about how the universe started. In popular parlance it's called the Big Bang Theory, but cosmologists call it the inflationary hypothesis. Some cosmologists have a lot of hubris and don't call it the inflationary hypothesis, but they call it "inflation" like it's an established fact. It's the idea that the universe was expanding in its earliest epoch.

According to the theory of inflation, the universe would expand, and so spacetime would expand uniformly but also through quantum mechanics cause some tremors in space time that are gravitational waves.These primordial gravitational waves were enormous in the early universe, but they died out. Actually they might still be observable, not by LIGO, but by its descendants. There is one called LISA [Laser Interferometer Space Antenna] which is supposed to go up in a few years. And there is something called the Big Bang Observer. I don't know when it'll ever go up, maybe 2035. Those could directly observe the primordial gravitational waves if it's there. But there's another way that you could observe it—it might get imprinted on the cosmic microwave background, which is the best source of information we have about the early universe.

The cosmic microwave background was created about 400,000 years after the Big Bang. The gravitational waves stream through space, and they imprint themselves on it. So you can look back at the moment of creation so to speak. In 2014, they thought they had observed this signal of primordial gravitational radiation. We didn't sleep for 48 hours, and we wrote a paper about something one could learn from this data. It turned out this was a complete mistake and it was really embarrassing because they had announced it. Not for me personally, because our paper was one of hundreds that people wrote in response to this incredible discovery. It probably would have been one of the greatest discoveries in all of science were it real, but when they are observing the cosmic microwave background, they are looking for a very particular pattern on it. But the same pattern is caused by all sorts of foreground effects that they have to worry about.

In most science you talk about the background noise, but in Cosmology, you talk about the foreground noise because you're trying to look into the past and everything that happened after it is in front of what you are looking at, and that is the foreground. So you have to somehow get rid of the foreground, and it turned out that what they were observing was actually dust in a galaxy. This is exciting for the handful of people who study dust in the galaxy, but for everyone else, it was a great disappointment and a great embarrassment because they had gone very public with this discovery announcement. For such an important matter, they were careless in estimating their foregrounds. They were in such a rush to announce it. They couldn't wait because there is this European collaboration called Planck which is a satellite that was collecting exactly the kind of data they were needing to estimate these foregrounds, but they were taking their own sweet time and they weren't sharing their data with the BICEP (Background Imaging of Cosmic Extragalactic Polarization) collaboration. BICEP partially fudged the data and someone took a picture of the Planck data at a talk with a phone camera, which you can imagine introduced distortions into the plot. That's where they got it all wrong.

Q: Do you have any advice for young scientists and undergraduates?

A: I guess I should avoid the cliches like, "go for what interests you," although that is certainly true. I've learned in my own life that you can. And I hadn't realized that that was possible. I think you, surprisingly as a young person, are much more conservative or unsure about what is possible. It's hard to believe that you can do the things that you want. But it turns out you can if you go for it, so I think you should.

The other advice I would give is, and this is specific to Case undergrads, that you have a lot of opportunities on this campus and you should make sure to seize them, but they require effort on your part. It's almost never going to happen that someone comes up to you and asks you, "Hey, do you want to work on a research project with me?" so it's up to you to identify who you might want to work with and then go out and make that happen. And explore widely as an undergraduate because there is going to be a period afterwards where you will have to narrow down. I think that was true in my life and it has to be true in anyone's life. For a while you have to become an expert in something before you can go back to being an expert in nothing and still make a living at it. So now is a great time to explore widely. Seize the opportunities and make sure you take initiative and also that you explore widely while you are young.