X-ray Tools Lesson, as told by Harvey Moseley

A Farm Education

I grew up on a farm in Virginia, where my family settled in the early 1700s. Next to our farm was a general store that my great grandfather started in 1872 when he came back from the Civil War. My dad ran the store and I worked there as a kid. There was a lot to do on the farm, mostly putting up hay and tending the cattle. When things were slow I also worked on repairing farm equipment. It was a surprisingly good education.

My dad was very knowledgeable, and he was interested in science. He still knew all of his math from school, like doing longhand square roots, which no one was taught to do when I was a kid. I could usually ask him for help with a math question, and he would know how to do it. And he was always fixing things. When you’re fixing something mechanical, you need to think about the problem and take a fairly scientific approach to solving it or else you’re going to spend a lot of time doing the wrong thing. This sort of analytical approach to problem solving is something I learned at a very early age.

But fixing mechanical things isn’t only about problem-solving. It also gives you something to think about. How do things work? How should they work? How *could* they work?

Leaving Home

I grew up in the 1950s, during Sputnik, when all of a sudden there was a big national focus on science. I liked math and was pretty decent at it, and I was fascinated by science. But when you grow up in a very rural place, you have no idea what the rest of the world is like. Thankfully, when I was in the ninth grade, the assistant principal pulled me aside and said I should start thinking about going to school somewhere that might have a more interesting curriculum. He gave me list of boarding schools and told me to write to them and see what I could find out. It was good advice, because I became a better student as I went through school by being more engaged by what I was learning. But it was tough going away to boarding school at 14 years old. My mother got sick with lung cancer about the time I left, and she died by the end of my first year there.

When I graduated from high school I didn’t know exactly what I was going to do. My girlfriend was applying to attend a women’s college in Connecticut. At this point she had been my girlfriend for a long time. We grew up together and she sat at the same table with me in first grade. I heard that the college was going to be coed the next year, so I applied there, too, and was accepted.

We went off to college together, and after graduation, we got married.

Coming to Chicago

We came to Chicago so I could attend graduate school at The University of Chicago. While I was a student, my wife and I lived at the University's Yerkes Observatory in Williams Bay, Wisconsin. Years after I got to know my NASA colleague, Neil Gehrels, I found out that he lived at Yerkes as a kid and actually slept in the same bedroom that our son did when we were living there! Small world.

I was at Chicago during the early years of far infrared astronomy. I worked with Al Harper at Yerkes flying experiments on the NASA Leer Jet. These were the first observations from above the water vapor in the atmosphere, so you could look at wavelengths that really weren't possible before. Then I flew experiments on the Kuiper Airborne Observatory for many years. When I finished my degree at Chicago, I had the opportunity to come to the NASA Goddard Space Flight Center to join a group here that was beginning to develop a satellite called a cosmic background explorer.

The *Cosmic Background Explorer*

The *Cosmic Background Explorer (CoBE)* mission was led by John Mather. The *CoBE* group was trying to figure out how to do measurements of the cosmic microwave background radiation. Even though the particular science I had been doing at Chicago was different, the techniques we had been using for infrared experiments were exactly what was needed to build the *CoBE*.

John developed a "theory of operation" for the detectors we were going to use on the *CoBE*. This is basically a mathematical description of how the device should work. At the time, John's wife was a ballet teacher in New York, and he would sit during her classes with a little programmable calculator (this was before there were laptops) to try to figure out the problem. This was a really different way of doing things, because people usually started by thinking about what detectors were going to be used, and what the different types of detectors were capable of doing, and where to buy them, and so on. But John was trying to develop a theoretical basis, so that you would understand how the performance of the detector could change if you modified the device in certain ways.

Detecting X-rays

At Goddard we worked down the hall from our colleagues in the X-ray group. We were testing a lot of stuff for the *CoBE* in advance of launching the instruments -- checking the susceptibility of our detectors to cosmic rays, and so on. We were detecting gamma rays using our instruments to see how they would respond so that we would know how they'd behave in space. We were also looking at various semi-conducting materials, like indium, for use in the detectors. The X-ray group down the hall was doing something similar, but using silicon diodes to detect X-rays.

One day the X-ray guys came down the hall -- they knew that we were looking at other semi-conductors rather than silicon -- and they asked me if I thought our indium detectors we were going to use for CoBE would be a good alternative to the silicon detectors for detecting X-rays. "Well, let me think," I said. "I don't think these indium detectors will work, but I have here in my drawer a calculation that shows that a thermal detector, where you measure the temperature change, will work very well for you." They couldn't believe it. So I said, "Let me see if I can find it, and then tomorrow I will come down and talk to you about it."

A Mathematical Answer

So I looked in my drawer, and there it was. I had the calculation because a year before a fellow from the National Institute of Standards and Technology called me and wanted to know how well we could measure pulses of laser light using a thermal detector, and I came up with a mathematical answer. Detecting the energy deposited from a single X-ray is exactly like that problem, so I had already solved the X-ray group's problem in a different guise. When I looked at my calculation, I realized that the thermal detectors would be perhaps 50 times better than what the silicon detectors were doing for X-ray detection.

Well, when I visited the X-ray group the next day they were rather incredulous -- but excited. So we tested out a few devices to see if they would work as expected. Things were so promising that the X-ray group put me in touch with Dan McHammond, from the University of Wisconsin, who turned out to be exactly the right guy to collaborate with on this.

Serendipity in Science

The next summer, Dan came out to Goddard and we lived in the lab for the entire summer and got the results using the microcalorimeter for X-ray spectroscopy for our first published papers. We pretty much knew we had an instrument that could work, so we proposed to use it on a space mission early the next year. We started getting funded at a pretty good rate, and the microcalorimeter technology developed relatively rapidly.

The technology that was pioneered for X-ray spectroscopy has really made a big difference, because it can be used for a wide range of applications. It's being used in dark matter detection, nuclear non-proliferation, and quantum computing. And we're using similar devices for doing measurements of the cosmic background radiation. We didn't anticipate that out of an attempt to do some spectroscopy.

This was one of those serendipitous moments in science, when there's someone trying to solve a problem and someone who has already solved it somehow coming together in an unexpected way. It was one of those things you couldn't plan for. This is why you have to have people thinking about how things work and inventing things, because you never know when the problem and the solution will meet up.

The *James Webb Space Telescope*

I started my career working on experiments in the infrared, and today I'm at it again, working on the *James Webb Space Telescope (JWST)* mission. The *JWST* telescope will have a near infrared camera, a mid-infrared instrument that includes both a camera and a spectrograph, and a near infrared spectrometer for doing spectroscopy of extremely distant, very old, and very dim galaxies. These are galaxies from a time when the universe was only a few hundred million years old. (It has reached 13.7 billion years now.)

John Mather is the senior project scientist for the *JWST*, so we're working together again. When the project was starting up, he said to me, "See if you can think of a way to do the spectroscopy for these distant galaxies." And I said, "Well, okay, I'll try." We figured out that we needed to be able to open up a slit on each galaxy and block the light from the others, and we came up with a micro-shutter array. It's really an amazing new technology. Microshutters "see" a dim object by selectively blocking out brighter sources of light in the cosmos. Each array of microshutters is about the size of a postage stamp arranged in a waffle-like grid. But each of these tiny square arrays contains 62,000 shutters that will function like tiny doorways, focusing the attention of the infrared camera on specific targets to the exclusion of others.

To get a good image of these very distant galaxies, it's going to take about 100,000 seconds of exposure time, which is a little over a day for a single galaxy. The advantage of the microshutter array is that it will let us look at 100 of these distant galaxies all at once. So the difference between looking at them one at a time compared to 100 at a time means we'll speed up the science goals of the program by about a factor of 100.

Advice to Young Scientists

There are a lot of myths about doing science. One is that science is for “somebody else” -- not me. Another is that anyone can do science. And then there’s the one that says if you are one of the somebody-else types, then science is easy for you. But that’s not true. A huge fraction of the work of scientists is hard work, even for scientists. The trick is, you have to be so enthusiastic about tackling the work that you’re willing to put the time in to do it. It’s an emotional investment.

You also want to be able to generate enthusiasm in other people. You have to convince people that, if something provides a fundamental advantage, you’re going to find a way to make it work. You’re not going to say, “We won’t do that, because it looks hard.” You persist because after you do something that’s hard for a while, then it’s not so hard anymore. Of course there’s hard and there’s impossible. The impossible you’re not going to do, but if it’s hard, if it provides some really fundamental advantage, then you work to develop the techniques to make it possible. The technical stuff you can learn to do, but to answer interesting questions you have to figure out how to improve upon something to solve your problem. That’s the thinking part, and it can be very hard but very rewarding.

The Nature of Scientific Inquiry

One of the other things I found out early on is that if you can duplicate what other people do really well, then it means that you have some understanding of the problem. That's the price of entry -- not trying to be different from the start. Find the best thing in the world, and then duplicate it. Once you can do that, then you can try some innovation.

When you work in science you also have to recognize there are a lot of important parts, and that the part you're doing is not the only one. This is something that's really important about working in teams. Every individual has to find a way to use his or her skills in a way that really benefits the project goals.

New technologies bring people together from wide ranges of fields.Things that cut in different directions are really important for innovation. The original question of how to measure the energy in a laser pulse sparked the idea of using microcalorimeters for X-ray spectroscopy, and this in turn enabled many types of research and technology development to move forward. That's why it's really important that people from sufficiently different contexts come together in science. Inquiry involves connecting things that are from very different phases of your experience and exploring and discussing them with a team of people with different ideas and experiences of their own. And through our work together, new ideas and solutions to old problems are born.