Geointeresting Podcast Transcript
Episode 5: Cleo Loi and Professor Steven Tingay
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Welcome to Geointeresting, presented by the National Geospatial-Intelligence Agency. Today on the show, we're joined by Ms. Cleo Loi and Professor Steven Tingay. Ms. Loi is an Australian astrophysicist who recently earned her bachelor's degree from the University of Sydney School of Physics. Professor Tingay is the director of the Murchison Widefield Array project and professor of radio astronomy at Curtin University. Stay tuned for Geointeresting.

NGA: Steven, I would like to start with you. Can you explain the Murchison Widefield Array?

Prof. Steven Tingay: The Murchison Widefield Array is a radio telescope. It operates at what astronomers would think of as low radio frequencies, at the 80 to 300 megahertz range. So this 80 megahertz is around about the frequency that FM radio operates at; just to give people a sense of where we are in the radio spectrum. So in astrophysics, this is considered low radio frequencies. When most people think about radio telescopes, they think about really large sort of satellite dishes; big curved dishes that focus radio waves. The MWA is quite different. It's called an interferometer; so this is where instead of one really large single dish antenna, we build out lots and lots of small antennas, distribute those antennas over many kilometers, and then combine the signals from those individual antennas to effectively produce a telescope that's equivalent to a really massive dish. We have 128 of those individual antennas, and they're distributed over a three-kilometer-diameter area.

The telescope is located in a quite remote area of Western Australia, called the Merch Essen. The Shire of the Merch Essen is the only Shire in Australia that does not have a gazette town, and it has an area of 41,000 square kilometers. It also has a population of around about 100 people. So that's the equivalent of having a population of 100 people in a country the size of the Netherlands. So it's a very, very sparsely populated area, and we need to be out in that part of the country to get away from all of the radio emissions that people generate with mobile phones, cars, microwave ovens; any sort of industrial activity. All of those things produce radio waves that are many, many times more powerful than the very weak radio waves that we're seeking to look at from the universe. It's also an interesting telescope in that the individual antennas have no moving parts, so instead of mechanically steering a large disc dish to look at different parts of the sky, all of our steering is done purely electronically. So it means it's a very easy telescope to build, very easy to operate, and very cheap and efficient to operate, which means that we can build a big telescope for not very much money. So it's sort of defining the future of how radio telescopes are going to look.

So the MWA is a precursor telescope for a much, much bigger telescope called the Square Kilometer Array. The MWA is primarily built to look at astrophysics. So the main science driver for the MWA is to tune into the signals generated by hydrogen gas in the first billion years of the life of the universe — the first billion years after the Big Bang — and watch how that gas evolves and produces the very first stars and galaxies and black holes. So the MWA, in a sense, is a time machine that's looking back to almost the very beginning of the universe and seeing where all of the stars and galaxies that we see around us now came from. So astrophysics is its main goal, but as we've operated the telescope over the last couple of years, the number of non-astrophysics applications have grown and grown and grown, and one of those is the detailed study of the ionosphere that Cleo's work has uncovered. And so what we're finding is that a lot of the science that we're doing with the MWA now is not necessarily the traditional astrophysics, but more of these fun non-astrophysics applications.

NGA: Cleo, can you explain the ionosphere; how does it affect your work?

Cleo Loi: So if you were to look through water…say you're at the bottom of a swimming pool, and you're trying to look at something that's above the surface. If you have waves in that pool, then that object or that person or something will look all rippled and distorted. This is the same physical process by which the ionosphere affects our images of the sky — the celestial sky, the universe — because we're looking from the ground through this ionosphere, which is a plasma. It consists of a gas of fluid where electrons have been ripped off neutral atoms and molecules, and those electrons interact with radio waves, and they bend the paths of radio waves much like water bends light. So it makes images of the universe appear to wobble around it, like how waves in the pool make images of things above that wobble.

NGA: How is this discovery made? Can you walk me through your timetable, starting with how your research began?

Cleo Loi: So the MWA began operations in mid-2013. I began my project as an undergraduate on this at the side of 2014, so it was six months after [the] telescope had begun operation did I actually [get] to have a look at the data, which was very exciting, so I basically had first dibs on this. My supervisor and her research group are focused on time-domain astrophysics. They look at exploding stars. Things are far away in space — they're not so interested in what's going on earth or with the ionosphere, but because the ionosphere affects our observations potentially in a damaging way, what she and her group wanted to know were how bad these effects were. So I was given the task of examining the data, having a look at measuring these distortions, and then giving them feedback on that. So when I did this analysis, I didn't know very much about the ionosphere at all, except that the earth has one, and I looked at the distortions that it was causing in the celestial sky, and I saw these incredibly organized structures that I was just knocked off my chair when I saw that for the first time. I wasn't expecting that at all. I had no idea what the ionosphere did on an everyday basis. And so that was incredible, and this was; I think it was in April, probably somewhere near the beginning of 2014, that I first saw this in the day and had no idea what they were. And it was after discussions with many people within the MWA collaboration and also researchers at other universities, including from NASA, that someone eventually suggested, "Could you be looking at these duct-like structures that people had been thinking existed?" and I went, "Oh, okay; well, I don't know what those are, but I'll have a look," and the properties matched perfectly. So I said, "I'll write a paper on this, and we'll get that out there so that the world knows about it."

NGA: Initially, your findings were met with skepticism. What's it like for a young scientist to have more experienced scientists dismissing your findings?

Cleo Loi: That was a strange experience; including my supervisor — she was also very skeptical towards that night. I suppose I did feel very vulnerable. I felt like I was alone because my research group had no interest in the ionosphere, so there's actually no one with any expertise and what it might or might not be doing, so I was really on my own then. I had the internet; that was about it for background knowledge. I guess there was also this frustration. It was like they just don't get it because I had reasons, actual reasons, for why I thought this was an earth-based phenomenon and not something caused by image problems or something in the celestial sky. So there was that frustration there. And so I did my best to explain this to them, and I guess they are good scientists, so it didn't take long before they were convinced that this was a real phenomenon. Although people still thought that the result was crazy; so did I, and so is everyone who's looked at the data.

Prof. Steven Tingay: Yeah, I'm not sure dismiss is the right word…

Cleo Loi: Not quite.

Prof. Steven Tingay: That the process was the classic scientific process…

Cleo Loi: Yes, it was a reasonable process.

Prof. Steven Tingay: …it really just got skepticism. And you need to be more skeptical the more exciting and new the result is. So I followed that email interaction and the interaction of you with the collaboration and other people, and it was a very, very healthy, very normal process applying the scientific method to a really new and exciting result. The difference was that as you say as an undergraduate, putting Cleo in that situation is very unusual, and in the process of Cleo answering everyone's questions — in comprehensive way and in detail and arguing a case. There was a reveal that Cleo is not your normal undergraduate student, but highly exceptional. So there was a very interesting experience to see that for the result itself, Cleo's part in it, and I think the way that the collaboration operated in applying a healthy skepticism. So I think it was a long way from just sort of dismissal.

NGA: You may have felt it was…

Cleo Loi: Well the email chain was actually the good bit where I got to have had the arguments in my head already and could form them and send them out to people. I guess the first dismissal was offline. And there was a teleconference where there were a couple of researchers and also my supervisor there, and I said that there's these crazy things in the sky, and they were like, “Oh, have you considered this problem, this problem, this problem?” and none of what they were saying was anything that might have included the possibility that there was a physical phenomenon. So I mentioned, “How about the magnetic field?” So I actually mentioned the magnetic field right at the start. That was one of my first — I guess, possibilities — that popped into my mind, but they were saying that magnetic field no name doesn't do anything like that. But these are not people who work in the field. So I did take that it wasn't something that's seen before, and so I shouldn't take it that it absolutely means it can't be the magnetic field, so there was that the experience.

NGA: That you use the Murchison Widefield Arra stereoscopically to achieve 3-D vision? Can you explain how that technique provided the breakthrough?

Cleo Loi: So the MWA has a finite size. It's spread over a region three kilometers across, and so you've got antennas or receivers that are separated on the ground. Now, if you want to know how far away an object is — I mean you think about your two eyes; they're separated by some distance on your head, and if you were to close one eye, open the other eye, you see an object that's fairly close by; close by enough to appear to shift. So that angular shift of the object in your field of view lets your brain work out half our waiters. So the MWA can be used in analogous manner. You've got something that's fairly close by; it's around the earth rather than in the distant universe. And so the signals recorded by the MWA antennas are all stored on disk, and you can retrieve those from your database, and you can group them according to where they come from on the ground. And when you do that, you form two sets of images; one from the left half of the array and one from the right half, and you see that there is a slight shift in the pattern that you see in the sky, and based on what you know about how far away those two groups of antennas are, you can use that to work out how high the structures are.

NGA: Was it a typical Eureka moment?

Cleo Loi: It was;it was incredible. Firstly, it was born of frustration, so I was thinking to myself, we want to publish these results, but we can't tell people how high they are and in what kind of — well it probably wasn't that bad, but I was just frustrated that we didn't have that crucial piece of information because it really sets the whole physical context of where they are in space. So I thought, okay, come on, there must be something we can do, and then I realized that, well; firstly, I thought to myself, maybe we can build another MWA, nix the first one, and use that distance between them to do the triangulation. I thought, hold on, the MWA itself has a number of antennas that are not all in one place. So what if we just split the MWA like that? And I said [this] in a shot of an email to the person who does imaging. She got back to me really quickly; she said, “That's a brilliant idea. I'll do it right away.” And then I got those results, I measure the shift, and I was like, “This actually works.” It was incredible.

Prof. Steven Tingay: I don't think that had ever been done before with a radio telescope, at least not that I'm aware of.

Cleo Loi: Not in the exact way, but the concept of parallax is not a new thing.

Prof. Steven Tingay: No, but with the radio telescope, I don't think that's ever been tried before. It must only be because the MWA has so many antennas that this is possible.

Cleo Loi: Yes, the MWA is unusual because it has hundreds — well, 128 — antennas. Most imaging arrays don't have that many, and you need lots of antennas to make a good image. So if you were to split another array and half it, it just wouldn't fare very well. So it's a technical capability that's helped there as well.

NGA: Dr. Tara Murphy, your undergraduate supervisor, said that your youth and inexperience, compared to other scientists, of course, was a benefit because you approach the problem without preconceptions. Do you agree?

Cleo Loi: In some ways, yes, because what she's talking about is the difference between an undergraduate student who's not sort of been immersed in a particular field of research for a long time but not someone who knows nothing because I did have to know some things about physics and the earth. But what she means is that if I was, for example, a space physics researcher that had been using a certain fixed set of techniques to study the earth, I would probably not be able to bridge the gap very easily into another community; which is radio astronomy, who operates these instruments. So there is a quite a big gap between the people who do ionospheric research and the people who work in astrophysics. They don't talk very much to each other, and so I would not have been able to firstly access the data if I was a researcher in the other field, and if I was a radio astronomer — as in some have been working in astronomy for a long time — I would see the ionosphere as being a problem and probably not be so curious or motivated to pursue the physics of what's going on.

NGA: So what does this mean? What do you expect to come out of this discovery? I've read that this could help the accuracy of GPS.

Cleo Loi: Well GPS satellites rely on radio-wave communication between space and the ground, and the presence of these structures distorts the signals. So you can get things like position errors because of the way the radio waves bend as they pass through these tubes. The main significant thing about this result, in my opinion, is the discovery of a capability of an instrument to look; to be able to cover the ionosphere so broadly and so much detail; to see structures like this for the first time, and that could be a starting point in, let's say — diagnosing where these occur, how often they occur; are there any predictive factors that might herald their appearance somewhere that we could look out for? and GPS signals during this time may be unreliable or that kind of thing. It wouldn't necessarily solve the problem, because it can't, but as a diagnostic tool, I think this is an incredible start.

Prof. Steven Tingay: Yeah, I think I largely agree with that, and Cleo's looked at a small fraction of all of our data. So who's to say that this is the last interesting effect that's going to be a new discovery out of these datasets? So I think we were only really starting to scratch the surface with what's possible here. What does it all mean? Well, the exciting answer to that for me is that I don't know, which means that we've got to come to places like the National Geospatial-Intelligence Agency to talk with experts who know a lot more about this, about why this could be really important. So I think it's a fantastic example of people from different disciplines coming together over a new result and learning things off each other. So the great thing is that I don't know, so that's always the best answer to a question because it means there's something new to discover or something new to learn about. But I really think we're just scratching the surface of the capabilities here, which means that whatever comes next might be even more exciting.

NGA: The Murchison Widefield Array have shown the value of next-generation radio telescopes; what's next?

Prof. Steven Tingay: Well, specifically, for us the future is the Square Kilometer Array. So the MWA has a few thousand individual antennas spread over three kilometers, and that's an official precursor telescope for this much, much larger square-kilometer array. So whereas the MWA costs 50 million dollars, Australian dollars, the SKA is a billion-euro-scale telescope. So the MWA is blazing the path for a much bigger array in Western Australia. So whereas MWA has a few thousand antennas, the first stage of the SKA will have about 100,000 antennas, and then the final instrument will have an order of 2 million antennas. So at the moment, we're collecting database data; data volumes of petabytes in size. So a petabyte is 1,000 terabytes, and a terabyte's 1,000 gigabytes, to give people an idea of the scale. But the SKA will deal in exabytes which are thousands of petabytes and beyond. So we're really on a big learning curve, and it's this new style of building highly capable, highly flexible telescopes with no moving parts that generate vast amounts of data and look at huge swathes of the universe in one go that are really going to uncover some of these fundamental questions of astrophysics, like, where did the first stars come from? what happened in the first billion years of the universe? But Cleo's work shows that instruments like the SKA will be incredibly exciting for things much closer to home, like the ionosphere, as well, so it's a very, very rich scientific future.

NGA: Thank you both for joining me today. For more information you can visit the arc center of excellence for all sky astrophysics at www.caastro.org, and for more information on the merchants and Widefield Array, visit www.mwatelescope.org. You can also follow Professor Tingay on Twitter at STINGAY. Thank you for listening to Geointeresting presented by the National Geospatial-Intelligence Agency. Never miss an episode of Geointeresting by subscribing on iTunes and SoundCloud. For more information on NGA, visit www.nga.mil and follow us on Twitter at NGA_G EOINT.