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"As you go towards the centre of our galaxy, things become more extreme in almost every way you can describe"

Nobel prizewinner **Andrea Ghez** provided the first proof that a supermassive black hole lurks at the centre of our galaxy. She tells Leah Crane how it was done

ROCIO MONTOYA

AT THE centre of our galaxy sits a colossal and mysterious black hole called Sagittarius A*. Astrophysicists now take that as a fact, but for decades we had little evidence for it because it is extremely difficult to observe the galaxy's bustling centre. It wasn't until 2000 that Andrea Ghez and Reinhard Genzel separately mapped the orbits of stars hurtling around the black hole. These orbits showed that the hidden object's mass was so huge and its size so small that there was nothing else it could be.

No one had thought it could be done. We simply didn't have the tools to observe individual stars in that congested area. But the researchers persisted, working with engineers to push the boundaries of astronomy. They pioneered the use of adaptive optics, a sophisticated technique to boost the capabilities of the biggest telescopes on Earth, so they could watch a series of stars circling very close to the centre of our galaxy for 10 years.

Along with Roger Penrose, who did earlier work showing that black holes are a robust prediction of general relativity, Ghez and Genzel each won a share of the 2020 Nobel prize in physics for their work. The pair provided the first real proof that supermassive black holes – which have masses more than 100,000 times that of the sun – exist. Ghez, based at the University of California, Los Angeles, continues to study Sagittarius A*, which may be the best way for us to understand these cosmic behemoths.

One particularly exciting opportunity is to use black holes to probe the vexing problem of how general relativity and quantum theory can be squared with one another. The areas surrounding a black hole are one of the few places where both theories are needed to describe what is going on. Ghez spoke with *New Scientist* about physics, winning the Nobel prize and the work she is doing now.

Leah Crane: What prompted you to start studying supermassive black holes?

Andrea Ghez: I think it was the early moon landings that first got me interested in astrophysics and thinking about the scale of the universe. What was bothering me was boundaries; the beginning and end of time and the boundaries of space. Black holes really capture a lot of those problems with space and time, especially with how general relativity and quantum mechanics come together, so I think that's originally what got me interested in black holes. They really represent the boundary of our understanding of how the universe works.

These monsters live at the centres of galaxies. What is that environment like?

In our galaxy, as you go towards the centre, things become much more extreme in almost any way you can describe. The density of stars increases, the speeds of stars increase and the strength of other characteristics, like their magnetic fields, increases. I like to think of it like an urban centre, and we're out here in the suburbs where everything's a little slower and calmer. The centre of the galaxy takes everything to the extreme, basically.

Is that what makes it so hard to study the area at the centre of our galaxy?

The centre of our galaxy has the advantage of being really close compared with the black › holes in other galaxies, so we have some advantages in terms of sorting out what's going on there. The disadvantage is that we're looking through the plane of our own galaxy to perceive what's at the centre.

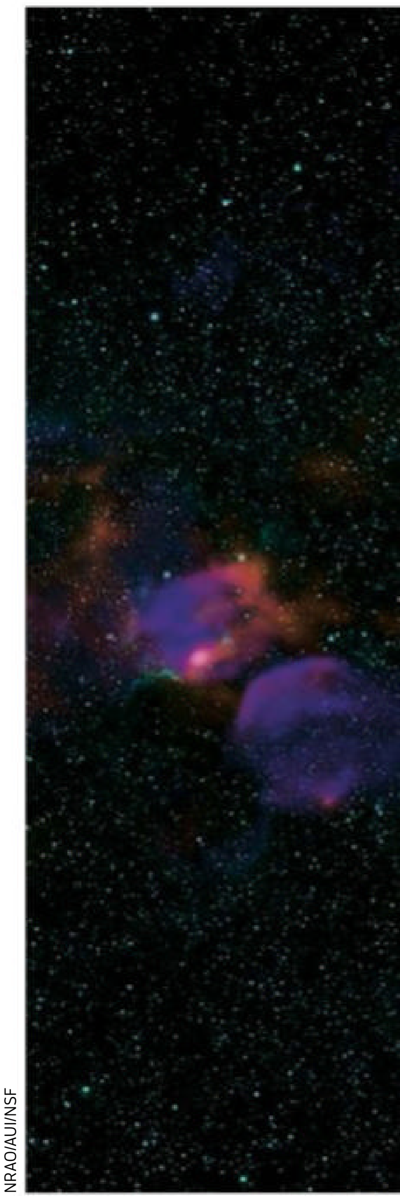
In addition to having a lot of stars in it, our galaxy also has a lot of dust. That dust makes it difficult for light that's emitted from the centre of the galaxy to reach us. If we were to try to look at the wavelengths that our eyes detect, we would perceive very little, because only one out of every 10 billion of these kinds of photons makes it to us.

So, it is less that there is so much going on there, more that there is stuff in between us and there?
Yes, although it is true that in the centre of the galaxy the crowding of stars becomes an issue as well. Of course, that just gets more and more problematic as the galaxy centre becomes further and further away. So our own galaxy is still our best hope for making any detailed measurements. But there are also technical challenges to that.

You are known for helping to pioneer a method that overcomes those challenges. Can you tell us about that?
When observing from ground telescopes, the atmosphere blurs the images. That makes it very difficult or impossible to distinguish stars at the heart of the galaxy from one another. There are two ways I like to think about the atmosphere. One is to think of it as a river. If you were to look at a pebble at the bottom of a river, it'd be hard to see because the water is moving and distorting your view. What you're trying to do is make that river stay still.

The second analogy is that you can think of the atmosphere as a circus funhouse mirror that makes everything look distorted. With adaptive optics, the technology that underlies most of my work, what you're trying to do is put a mirror on the telescope that has the opposite shape and makes things look flat again. That mirror has to move very quickly to keep up with what the atmosphere is doing, but there's so much more information that you can get with this more sophisticated technique.

"It's surreal to get the Nobel prize, period. To get it in the middle of the pandemic adds another element of surrealism"



NRAO/AUI/NSF

And it's not like we can stop that river or fix the funhouse mirror. We do need it to be alive.
Yes, the atmosphere is great for us. But it is a total headache in terms of astronomical imaging.

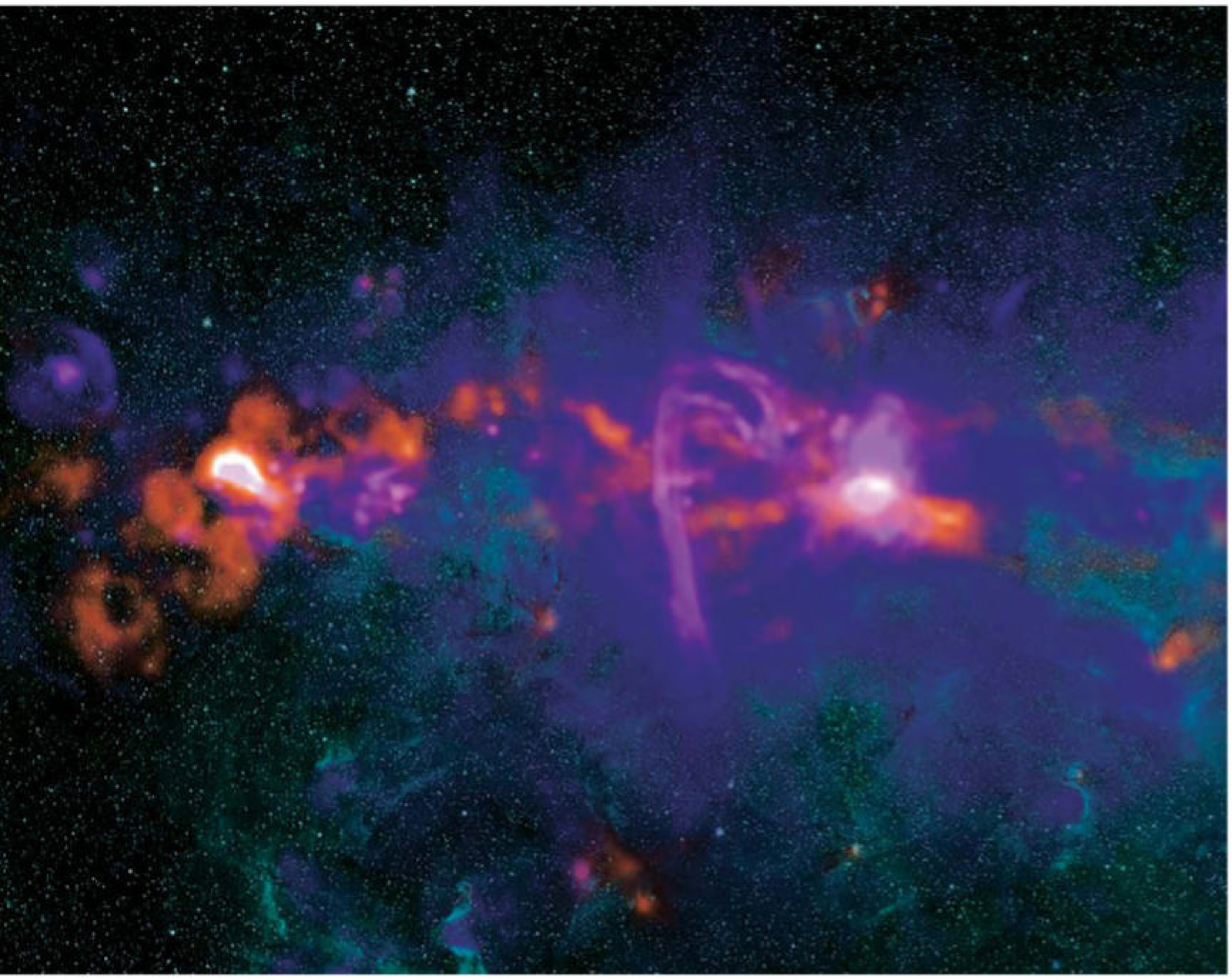
It seems like a lot of our best knowledge about Sagittarius A* comes from just a few stars, including your work. Why is that?
That's an interesting perception. I say perception because it is true that today there is one star that is, so to speak, the star of the show, called S0-2. It is absolutely my favourite star in the universe. But we are measuring thousands of stars, and they're all important, they just have different roles to play. Behind those measurements of S0-2, you need stars that tell you how to line up these images across all your observations. So many stars are playing what I would call supporting roles, but they are still absolutely essential.

So, it isn't a one-star show, but there is one that is the star of the show?
There is a prima donna in the room. It has a really short orbit, and what I mean by "really short" is shorter than a human lifetime or maybe a career. It only takes about 16 years for S0-2 to complete an orbit of Sagittarius A*. To put this in context, the sun takes 200 million years to go around the centre of the galaxy. You are not going to wait for that to happen or try to see the curvature of that orbit. It's the orbits of S0-2 and a few other stars like it that give us evidence that there must be a compact, massive object – a black hole – there.

What was it like when you finally got that proof that there was, in fact, a supermassive black hole at the centre of our galaxy?
Oh my goodness, this has been such an exciting project to do because every stage of making progress towards the answer to the question "is there a supermassive black hole?" has been so much fun and so exciting. There's nothing like doing a project where people don't think it's going to work.

Especially if it works.
If it works, yes. And it did!

Speaking of exciting, how has it been since you won the Nobel prize?
It has been surreal. It's surreal to get the Nobel prize, period. It's something that I never anticipated. To get it in the middle of the pandemic adds another element of surrealism to already surreal times. It was really lovely to



The centre of our Milky Way galaxy, where a huge and mysterious black hole lurks

have good news to share with friends and family and colleagues during these hard times.

All of a sudden, there are a lot of opportunities and invitations to do things, and it forces you to think: what are you going to do now? What are your responsibilities that are associated with receiving a prize like this? What are the opportunities that you want to pursue? I really feel strongly about both taking some of the responsibilities of being a spokesperson for science, but also continuing to pursue the cool questions at the centre of the galaxy.

I would like to ask you about that responsibility. A lot of women in the sciences, particularly in physics, can feel unwelcome. How can we make the field more accessible and welcoming to everyone?

I think the best thing that you can do is do good science, to show that women can be just as effective at being a scientist as anyone else can. The more women that succeed at the very top, the more I think it helps the field change just through demonstration. And that demonstration is partially for your peers, but probably more importantly, it shows the next generation the possibilities. In my book, the best way you can change the field is by having the people who are in the minority succeeding.

What are you working on at the moment?

Quite a few things. It's all really a continuation of this work at the centre of the galaxy, building on our ability to make precision measurements of orbits. At the moment, we're trying to measure what's known as the precession of the periapsis, which is how the orbit of a star as a whole rotates. That allows you to ask two questions: how does gravity work in the vicinity of the black hole; and is there dark matter surrounding it?

We're at that phase now where things are emerging, and I'm not sure what's right and what's not. I love this part of science. There's a potential for new understanding, and it's just messy. Our job is to sort out the mess.

"Black holes represent the boundary of our understanding of how the universe works"

You have the pile of puzzle pieces.

Exactly. I love puzzles. And I have to say, the centre of the galaxy just keeps getting more interesting. This is a project I thought was going to be three years long, and here, 25 years later, I'm still excited and it's still giving.

Thinking about black holes, what is the next big question we need to answer?

There are lots. We still don't understand what a black hole is – that is certainly a big question. How do we make quantum mechanics come together with general relativity to explain these objects? I think that is an enormous question that really drives so much of our work. We're still nowhere near answering it. ∎

Leah Crane is a reporter for *New Scientist*. Sign up to her newsletter about space at newscientist.com/sign-up/launchpad