

ASTRONOMY BEHIND THE HEADLINES
A podcast for Informal Science Educators
from the Astronomical Society of the Pacific

www.astrosociety.org/abh



Episode 5: MEASURING THE BLACK HOLE
with Dr. Shep Doeleman, MIT's Haystack Observatory

Written by Carolyn Collins Petersen

Music by GEODESIUM

Soundtrack production by Loch Ness Productions

Produced by the Astronomical Society of the Pacific

HOST: Welcome to Astronomy Behind the Headlines, a podcast by the Astronomical Society of the Pacific.

The Milky Way Galaxy has a black hole at its heart — an object called Sagittarius A*. We can't see it visually, but radio astronomers can easily spot it. A group led by Dr. Shep Doeleman at MIT's Haystack Observatory made a startling measurement of the accretion disk around Sagittarius-A-star. We talked with Dr. Doeleman about his team's discovery.

Dr. Doeleman, first, let's talk about black holes — and in particular, the one at the heart of the Milky Way Galaxy

SHEP DOELEMEN: Black holes are what you get when matter becomes so dense and crunches in on itself, that there's a runaway reaction, and it dissolves into a singularity. Matter becomes so dense that even light cannot escape from its gravitational pull.

And there's something around the black hole called the event horizon. And that's the exact point at which the speed of light is not sufficient to escape from the black hole. So, within the event horizon, anything that falls in there is lost to us forever. We can't get any information out.

Black holes used to be very exotic constructs, but now we understand them as being part of a zoo that exists in our universe. They're really part of the explanation for many things that happen in our universe. So, when stars die, the cinders of those stars can become black holes. But, also there are million-solar-mass or even billion-solar-mass black holes that exist in the centers of galaxies, and that affect how the galaxies evolve over time. So, they're very much part of the fabric of our universe.

HOST: So how do we see a black hole? If they're black how do we detect them?

SHEP DOELEMEN: That's a very interesting question and one that comes up a lot. Imagine that there's a black hole and it's attracting matter because of its intense gravitational pull. Well, all that matter starts to flow towards the black hole and it gets into a smaller and smaller and smaller space and starts interacting with itself, and it starts to glow. It starts to heat up and become luminous.

So, we don't actually see what's inside of a black hole. We don't see the black hole itself, we see the effect it has on all the matter and the gas around it, which becomes so hot — white hot — it glows across many wavebands from gamma rays to x-rays to radio waves. And, we can see it with a number of different kinds of telescopes available to astronomers.

HOST: How do you go about measuring the size of a black hole?

SHEP DOELEMEN: To measure the size of a black hole is a very, very tricky thing. One of the “Holy Grails” in astronomy is to be able to image a black hole with a sharpness of detail or resolving power that would let you actually see that event horizon boundary that I talked about.

One of the best candidates in the universe — probably the best candidate — happens to be in our own back yard. In the center of the Milky Way is a four-million-solar-mass black hole that presents to us the biggest event horizon of any black hole candidate that we know of. And, if we were able to resolve that, if we were able to make an image of that, we’d be able to answer questions about general relativity, Einstein’s theory of gravity — where gravity becomes very, very strong. And also about how black holes eat — how they accrete or attract matter, and how they also form very powerful outflows that we see from the centers of galaxies.

So, Sagittarius A* is this black hole in the center of the Milky Way galaxy and we’re focused on that because it’s our best hope of resolving the event horizon.

The problem is that between us and the black hole itself is a lot of gas and dust. If you looked at the center of the galaxy with the naked eye, you wouldn’t be able to see the region around the black hole. But, radio waves CAN penetrate all of that gas and dust. So, we use radio waves to try to “sense” the black hole.

In order to get the sharpness of detail we require, we take radio telescopes — not in one area, but we spread them out around the globe. So, we use telescopes in Hawai’i and in California. They observe the black hole at the same time, and the data from both those sites are brought together to a central facility, where they’re processed, and we can make

a picture of the black hole as though we had a telescope as large as the distance between those telescopes. So imagine we had a telescope as large as the distance between Hawai'i and California — that's what we're doing.

And, using this technique that we call “very long baseline interferometry” tying together telescopes gives us the resolving power we need to image the event horizon.

HOST: What did you find?

SHEP DOELEMEN: We used three telescopes — one in Hawai'i, in California and one in Arizona to observe the black hole. We found an extremely compact source — a very, very small source. The very interesting thing about this finding is that the size we found is almost embarrassingly small. It was really tiny. And the reason it was really tiny is that even if you had emission right around the edge of the event horizon of the black hole, it would seem much larger to us than the event horizon.

Why? Because the extreme gravity of the black hole bends light, so the black hole appears to be much larger than it is. We would expect a minimum size for something like that. The size that WE measured with very long baseline interferometry was much smaller than that. And from this, we understand that we're not looking at a luminous surface surrounding a black hole, but probably we're looking at a bright source just off to one side of the black hole. And we understand that because when a black hole eats, it funnels all the matter that it's eating into a pancake kind of disk that's orbiting the black hole, which we call the accretion disk. And, one side of the disk is coming towards us, and the other side of the disk is receding from us — moving away from us at very, very high speeds, extreme speeds near the speed of light.

So the side of the accretion disk that's coming towards us is amplified by the Doppler effect, in much the same way that a whistle on an oncoming train sounds higher in pitch and a whistle that's moving away from you sounds lower in pitch.

So, we would expect to see a bright spot off to one side — which is roughly consistent with what we see. So we think we have evidence now for seeing one part of an accretion disk around this very, very massive black hole.

HOST: What's emitting the radio waves you detected?

SHEP DOELEMEN: The accretion disk itself is emitting radio waves all the time. But because the accretion disk is spinning around the black hole, we preferentially only see one little spot of the accretion disk that's moving towards us at very high speeds. All the rest of the disk that's moving away from us or off to one side, we don't see very much at all because it's not amplified in our direction via the Doppler Effect.

HOST: So, this is quite a step forward — measuring the accretion disk and the spot?

SHEP DOELEMEN: I have to say I think it's very huge — it's very important. People attack black holes from a lot of different directions. There are theoretical astronomers that try to attack the theory and understand that better. People are trying to look at black holes all across the electromagnetic spectrum, from infrared waves to x-rays.

What this does that no other technique can deliver is to give the angular resolution to image the black hole itself — to see how matter orbits the black hole. And if we can do that, there's one thing that we're really hoping to see — and that is the shadow of the black hole. Because when you surround a black hole by this accretion disk, you expect that towards the black hole you don't see much. And that's because the light coming to us from just in front of the black hole, has to fight its way out of a very deep gravitational well. So, it seems faint.

But the light that is emitted from behind the black hole is bent around by the extreme

gravity of the black hole to make a luminous ring around the event horizon. So, you wind up seeing something that looks almost like a donut — the ring region that's very bright, and a shadow in the middle. And, if we can measure the size and shape of that shadow, then we can directly test Einstein's predictions for the way matter and light should behave right around a black hole.

HOST: So, what's the next step?

SHEP DOELEMEN: The next step is to add more telescopes. Right now we only have three telescopes, so we can get a good idea of the size of the emission region around the black hole. But to really image the black hole, and to test for signatures that show that matter is orbiting the black hole before it spirals into the event horizon — for that, we need a few things. One is more telescopes so we can get better images.

And, we need to increase the sensitivity of those telescopes so we can look for fainter emission features. And, we need to go higher in frequency. So right now we're at a fairly high frequency of 230 GHz (gigahertz), which in the radio regime is fairly high. And, we'd like to observe at even higher frequencies that will give us better angular resolution, or more resolving power to let us see even smaller details.

HOST: You can learn more about Sagittarius A* and Dr. Doeleman's radio observations, at the Astronomical Society of the Pacific's Astronomy Behind the Headlines web page at www.astrosociety.org/abh. Thanks for listening!

Special thanks to Dr. Shep Doeleman