AstroTalk: Behind the news headlines; June 2022

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Black holes galore

A team led by researchers at the University of North Carolina (USA) has found a previously overlooked treasure trove of massive black holes in so-called 'dwarf' galaxies. The newly discovered black holes offer a glimpse into the life story of the supermassive black hole at the centre of our own Milky Way galaxy.

As a giant spiral galaxy, the Milky Way is believed to have been built up from mergers of many smaller dwarf galaxies. For example, the Magellanic Clouds, some of our nearest galaxies visible in the southern sky, are dwarf galaxies that will eventually merge with the Milky Way. Each dwarf galaxy that falls in may bring with it a central massive black hole, tens or hundreds of thousands of times the mass of our Sun, potentially destined to be swallowed by the Milky Way's central supermassive black hole.

But how often dwarf galaxies contain a massive black hole is unknown, leaving a key gap in our understanding of how black holes and galaxies grow together. New, recently published research helps to fill in this gap by revealing that massive black holes are many times more common in dwarf galaxies than previously thought.

> "*This result really blew my mind because these black holes were previously hiding in plain sight*," said Mugdha Polimera, lead author of the new study.

Black holes are typically detected when they are actively growing by ingesting gas and stardust swirling around them, which makes them glow intensely.

Professor Sheila Kannappan, Polimera's Ph.D. advisor, compared black holes to fireflies.

> "*Just like fireflies, we see black holes only when they're lit up—when they're growing—and the lit-up ones give us a clue to how many we can't see*."

The problem is, while growing black holes glow with distinctive high-energy radiation, young newborn stars can too. Traditionally, astronomers have differentiated growing black holes from new star formation using tests that rely on detailed features of each galaxy's visible light when spread out into a spectrum, like a rainbow.

The path to discovery began when undergraduate students working with Kannappan tried to apply these traditional tests to galaxy survey data. The team realised that some of the galaxies were sending mixed messages—two tests would indicate growing black holes, but a third would indicate only star formation.

"*Previous work had just rejected ambiguous cases like these from statistical analysis, but I had a hunch they might be undiscovered black holes in dwarf galaxies*," Kannappan said.

She suspected that the third, sometimes contradictory, test was more sensitive than the other two to typical properties of dwarf galaxies: their simple elemental composition (mainly hydrogen and helium left over from the Big Bang) and their high rate of forming new stars.

Study co-author Chris Richardson confirmed using theoretical simulations that the mixed-message test results exactly matched what theory would predict for a highly star-forming dwarf galaxy containing a growing massive black hole.

"*The fact that my simulations lined up with what the Kannappan group found made me excited to explore the implications for how galaxies evolve*," Richardson said.

Polimera took on the challenge of constructing a new census of growing black holes, with attention to both traditional and mixed-message types. She obtained measurements of visible light spectral features to test for black holes in thousands of galaxies found in two surveys, ***RESOLVE*** and ***ECO***.

These surveys include ultraviolet and radio data ideal for studying star formation, and they have an unusual design. Whereas most astronomical surveys select samples that favour big and bright galaxies, ***RESOLVE*** and ***ECO*** are complete inventories of huge volumes of the present-day Universe in which dwarf galaxies are abundant.

"*It was important to me that we didn't bias our black hole search towards dwarf galaxies*," Polimera said. "*But in looking at the whole census, I found that the new type of growing black holes almost always showed up in dwarfs. I was taken aback by the numbers when I first saw them*."

More than 80 per cent of all growing black holes she found in dwarf galaxies belonged to the new type.

The result seemed too good.

"*We all got nervous*," Polimera said. "*The first question that came to my mind was: Have we missed a way that extreme star formation alone could explain these galaxies?*"

She led an exhaustive search for alternative explanations involving star formation, modelling uncertainties or exotic astrophysics. In the end, the team was forced to conclude that the newly identified black holes were real.

"*We're still pinching ourselves*," Kannappan said. "*We're excited to pursue a zillion follow-up ideas. The black holes we've found are the basic building*

> *blocks of supermassive black holes like the one in our own Milky Way. There's so much we want to learn about them*."

Independently, meanwhile, another team also focused on black holes hiding in dwarf galaxies—with potentially ground-breaking results.

Their idea was that the discovery of a supermassive black hole in a relatively small galaxy—a dwarf galaxy, for instance—could help astronomers unravel the mystery surrounding how the very biggest black holes grow.

The researchers used NASA's *Chandra* X-ray Observatory to identify a black hole containing about 200,000 times the mass of the Sun buried in gas and dust in the galaxy Markarian (Mrk) 462.

Mrk 462 contains only several hundred million stars, making it a dwarf galaxy. (By contrast, our Milky Way is home to a few hundred billion stars.)

This is one of the first times that a heavily buried, or 'obscured', supermassive black hole has been found in a dwarf galaxy.

> "*This black hole in Mrk 462 is among the smallest of the supermassive, or monster, black holes*," said Jack Parker of Dartmouth College (USA), who led the study. "*Black holes like this are notoriously hard to find*."

In larger galaxies astronomers often find black holes by looking for the rapid motions of stars in the centres of galaxies. However, dwarf galaxies are too small and dim for most current instruments to detect this. Another technique is to search for the signatures of growing black holes, such as gas being heated up to millions of degrees and glowing in X-rays as it falls towards a black hole.

The researchers in this study used *Chandra* to look at eight dwarf galaxies that had previously shown hints of black hole growth from optical data gathered by the Sloan Digital Sky Survey. Of those eight, only Mrk 462 showed the X-ray signature of a growing black hole.

The unusually large intensity of high energy X-rays compared with low energy X-rays, along with comparisons with observations at other wavelengths, indicates that the Mrk 462 black hole is heavily obscured by gas.

> "*Because buried black holes are even harder to detect than exposed ones, finding this example might mean there are a lot more dwarf galaxies out there with similar black holes*," said Parker's colleague Ryan Hickox.
>
> "*This is important because it could help address a major question in astrophysics: How did black holes get so big so early in the Universe?*"

Previous research has shown that black holes could grow to a billion solar masses by the time the Universe was less than a billion years old, a small fraction of its current age of 13.7 billion years.

One idea is that these huge objects were created when massive stars collapsed to form black holes that weighed only about 100 times the mass of the Sun. Theoretical work, however, struggles to explain how they could pack on weight quickly enough to reach the sizes seen in the early Universe.

An alternative explanation is that the early Universe was seeded with black holes containing tens of thousands of solar masses when they were created—perhaps from the collapse of gigantic clouds of gas and dust.

The presence of a large fraction of dwarf galaxies with supermassive black holes favours the idea that small black hole seeds from the earliest generation of stars grew astonishingly quickly to form the billion solar mass objects in the early Universe. A smaller fraction would tip the scales to favour the idea that black holes began life weighing tens of thousands of Suns.

These expectations apply because the conditions necessary for the direct collapse from a giant cloud to a medium-sized black hole should be rare, so it is not expected that a large fraction of dwarf galaxies would contain supermassive black holes. Stellar-mass black holes, on the other hand, are expected in every galaxy.

> "*We can't draw strong conclusions from one example, but this result should encourage much more extensive searches for buried black holes in dwarf galaxies*," said Parker. "*We're excited about what we might learn*."

But let's not forget that there are numerous black holes in the Universe that actually shine bright and are much easier to spot. Recently, astronomers have developed a new way of detecting 'active' black holes in the Universe and measuring how much matter they are sucking in.

The technique can be applied to millions of galaxies, searching for bright, supermassive black holes at the centres of galaxies.

Study lead Jessica Thorne, at the University of Western Australia, said active black holes are typically found in the largest galaxies in the Universe.

> "*The black holes we're looking for are between a million and a billion times more massive than our Sun*," she said.
>
> "*As they suck in matter from around them, the matter gets super-heated because of friction and becomes very, very luminous*."
>
> "*And when they're active, these black holes can outshine the rest of the galaxy*."

Until now, identifying bright black holes has been challenging, with astronomers having to specifically look for them using complex methods unique to different types of telescopes.

Instead, the new technique works on typical telescope observations that already exist for millions of galaxies.

> "*We can identify these active black holes and look at how much light they're emitting, but also measure the properties of the galaxy it is in at the same time*," Thorne said.
>
> "*By doing both at once, we can have a better idea of exactly how the black hole is impacting its host galaxy*."

The researchers developed a new technique to model emission from galaxies and black holes at different wavelengths of light. They then applied the method to almost half a million galaxies from the Anglo–Australian Telescope's ***DEVILS*** survey.

They also applied it to more than 200,000 galaxies from the ***GAMA*** survey, which brings together observations from six of the world's best ground and space-based telescopes.

Thorne's University of Western Australian colleague, Dr. Sabine Bellstedt, said scientists often fail to account for bright black holes in galaxies.

> "*One of the reasons we've ignored them in the past is because it's hard to find them all*," she said.
>
> "*We don't really understand these bright black holes well enough to incorporate them into our modelling with sufficient detail*."

Dr. Bellstedt said the new technique is easier, more consistent and more thorough.

> "*It suddenly means we can look for active black holes in so many more places than we were able to before*," she said.
>
> "*It's going to help us search more galaxies, and look further back in time to the distant Universe*."

Supermassive black holes are thought to have a huge impact on how galaxies evolve.

> "*We think that an active black hole in a galaxy is able to decrease the amount of star formation really quickly and stop the galaxy from growing any further*," Thorne said. "*It can effectively kill it*."

With observations from new telescopes such as the James Webb Space Telescope, the Vera C. Rubin Observatory in Chile, and the Square Kilometre Array, in both Australia and South Africa, astronomers may be able to apply the technique to millions of galaxies at once.

"It's exciting to think about how many doors this has unlocked for the future," Thorne said.

Fig. 1: The newly discovered massive black holes reside in dwarf galaxies, where their radiation competes with the light of abundant young stars. (*Credit: NASA & ESA/Hubble, artistic conception of black hole with jet by M. Polimera*)

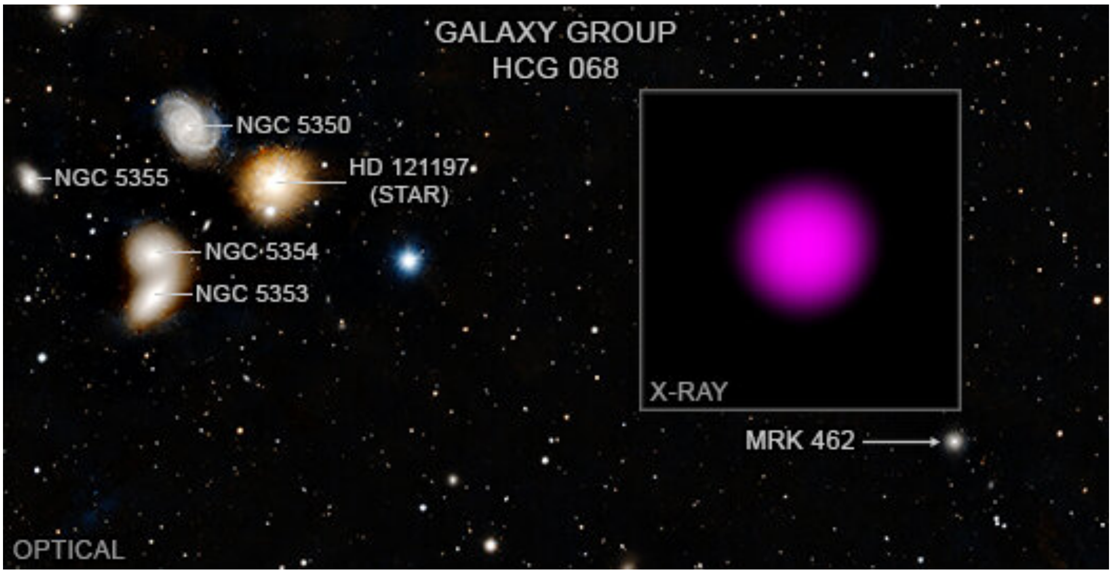

Fig. 2: The dwarf galaxy Mrk 462. (*Credit: X-ray: NASA/CXC/Dartmouth Coll./J. Parker & R. Hickox; Optical/IR: Pan-STARRS*)

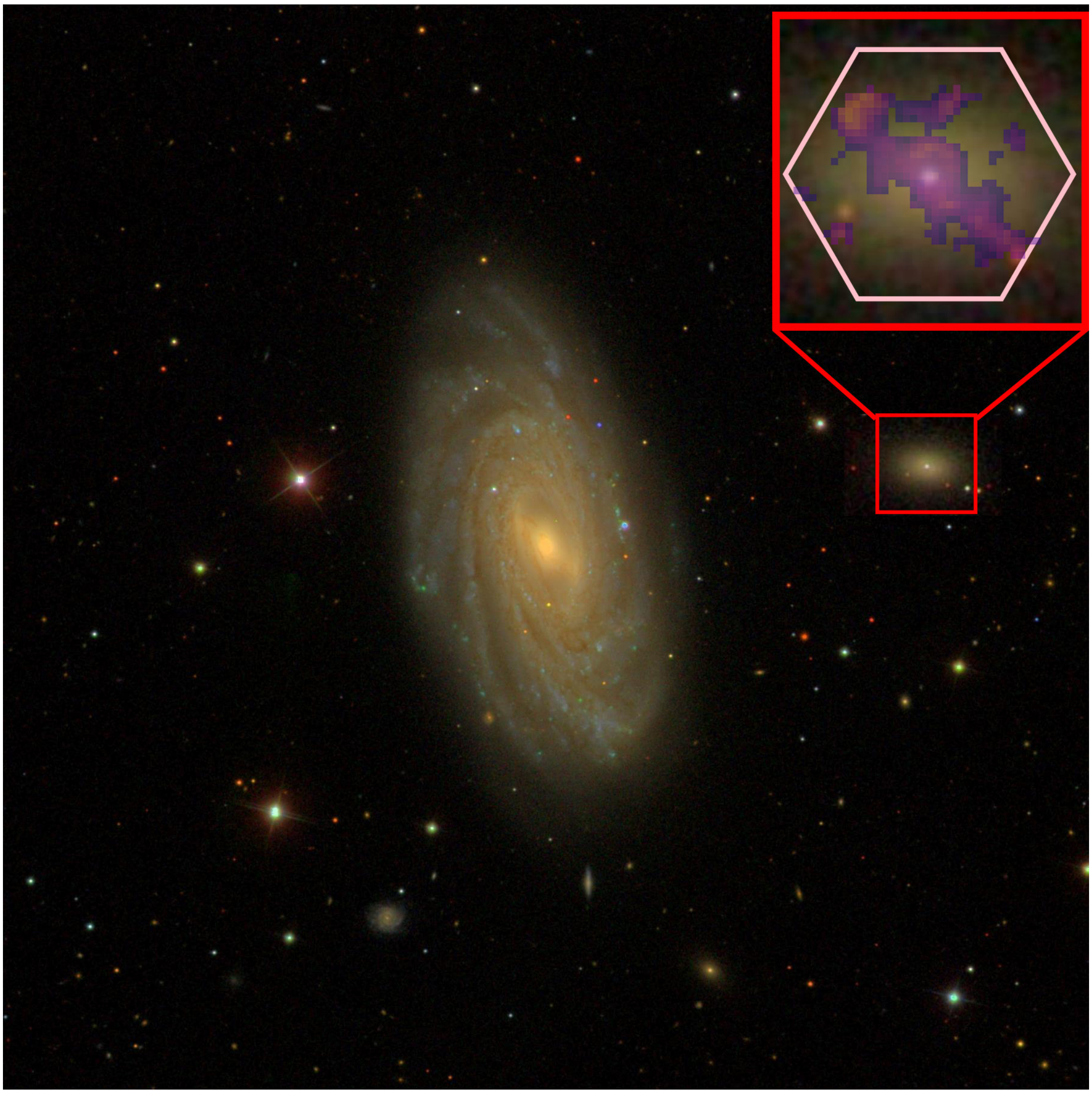

Fig. 3: Size comparison of a dwarf galaxy (right inset, bottom) with a larger galaxy in the centre. Top inset: Dwarf galaxy overlain with MaNGA data, revealing the winds from the supermassive black hole. *Credit: Samantha Penny (Institute of Cosmology and Gravitation, University of Portsmouth) and the SDSS collaboration*

Fig. 4: Dwarf galaxy NGC 4395, about 13 million light-years from Earth, known to harbour a black hole some 300,000 times more massive than the Sun. It is a prototypical example of a small galaxy once thought to be too small to contain such a black hole. (*Credit: David W. Hogg, Michael R. Blanton, and the Sloan Digital Sky Survey Collaboration; NRAO/AUI/NSF*)

Fig. 5: The dwarf galaxy Henize 2-10, seen in visible light by the *Hubble Space Telescope*. The central, light-pink region shows an area of radio emission, observed with the Very Large Array. This area indicates the presence of a supermassive black hole drawing in material from its surroundings. This also is indicated by strong X-ray emission from this region detected by the *Chandra* X-Ray Observatory. (*Credit: Reines, et al., David Nidever, NRAO/AUI/NSF, NASA*)

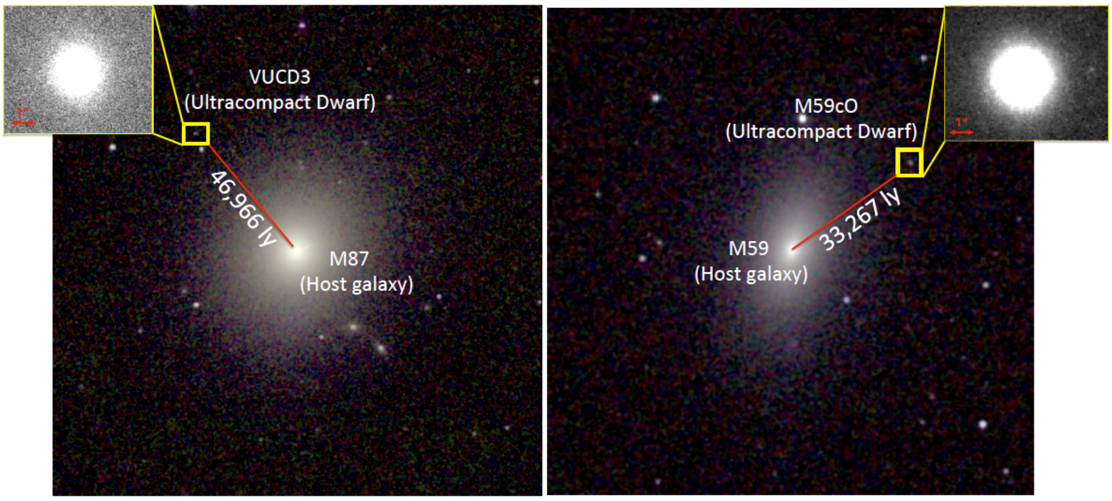

Fig. 6: Astronomers have found two ultra-compact dwarf galaxies, VUCD3 and M59cO, with supermassive black holes. The findings suggest that the dwarfs are likely tiny leftovers of larger galaxies that were stripped of their outer layers after colliding into other, larger galaxies M87 and M59, respectively. (*Credit: NASA/Space Telescope Science Institute*)