<u>AstroTalk: Behind the news headlines; March 2022</u>

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Now you see them, now you don't: the elusive nature of nearby black holes

In 2020, a team led by European Southern Observatory (ESO) astronomers excitedly reported the closest black hole to Earth, located just 1,000 light-years away in the stellar system known as HR 6819. The object thought to be a black hole was closer to our Solar System than any other found to date and forms part of a triple-star system. Located in the constellation *Telescopium*, the system is so close to us that its stars can be viewed from the southern hemisphere on a dark, clear night without the need for a telescope or even binoculars.

But the results of that 2020 study were contested almost immediately by other researchers. In an article published in early March 2022, two of the competing teams finally united to report that there is, in fact, no black hole in HR 6819, which is instead a 'vampire' two-star system in a rare and short-lived stage of its evolution.

The original study on HR 6819 received significant attention from both the press and scientists. Thomas Rivinius, an ESO astronomer and lead author on that paper, was not surprised by the astronomy community's reception of their claimed discovery of the black hole. "*Not only is it normal, but it should be that results are scrutinised*," he said, "*and a result that makes the headlines even more so*."

Rivinius and his colleagues were convinced that the best explanation for the data they had was that HR 6819 was a triple system, with one star orbiting a black hole every 40 days and a second star in a much wider orbit. The team had found evidence for the invisible object by tracking its two companion stars using the MPG/ESO 2.2-metre telescope at ESO's La Silla Observatory in Chile. They said at the time that this system could just be the tip of the iceberg, as many more similar black holes could be found in the future.

> "*We were totally surprised when we realised that this [was] the first stellar system with a black hole that can be seen with the unaided eye*," said co-author Petr Hadrava, Emeritus Scientist at the Academy of Sciences of the Czech Republic.

The team originally observed the HR 6819 system as part of a study of double-star systems. However, as they analysed their observations, they were stunned when they revealed a third, previously undiscovered body in HR 6819. Their observations showed that one of the two visible stars orbits an unseen object every 40 days, while the second star is located at a large distance from this inner pair.

The researchers said that if the hidden object in HR 6819 was a black hole, which was clearly their preferred explanation at the time, it would be one of the very first stellar-mass black holes found that do not interact violently with their environment and, therefore, appear truly black. But the team could spot the object's presence and calculate its mass by studying the orbit of the star in the inner pair. "*An invisible object with a mass at least 4 times that of the Sun can only be a black hole*," concluded Rivinius at the time.

Astronomers have spotted only a couple of dozen black holes in our Milky Way galaxy to date, nearly all of which interact strongly with their environment and make their presence known by releasing powerful X-rays in these interactions. But scientists estimate that, over the Milky Way's lifetime, many more stars must have collapsed into black holes as they ended their lives. The discovery of a silent, invisible black hole in HR 6819 would have provided clues about where the many hidden black holes in the Milky Way might be found.

> "*There must be hundreds of millions of black holes out there, but we know about only very few. Knowing what to look for should put us in a better position to find them*," said Rivinius after the original discovery paper was published.

Indeed, the astronomers believed that their discovery could shine some light on a second system.

> "*We realised that another system, called LB-1, may also be such a triple [system], though we'd need more observations to say for sure*," said Marianne Heida, a postdoctoral fellow at ESO and also a co-author of the original paper. "*LB-1 is a bit further away from Earth but still pretty close in astronomical terms, so that means that probably many more of these systems exist. By finding and studying them we can learn a lot about the formation and evolution of those rare stars that begin their lives with more than about 8 times the mass of the Sun and end them in a supernova explosion that leaves behind a black hole*."

Discoveries of such triple systems with an inner pair and a distant star could also provide clues about the violent cosmic mergers that release gravitational waves powerful enough to be detected on Earth. Some astronomers believe that the mergers can happen in systems with a similar configuration to HR 6819 or LB-1, but where the inner pair is made up of two black holes or of a black hole and a neutron star. The distant outer object can gravitationally impact the inner pair in such a way that it triggers a merger and, subsequently, the release of gravitational waves. Systems like HR 6819 and LB-1 could help scientists understand how stellar collisions can happen in triple star systems.

However, after all this excitement and media attention, a study led by Julia Bodensteiner, then a Ph.D. student at KU Leuven (Belgium), proposed a completely different explanation for the same data: HR 6819 could also be a system with only two stars on a 40-day orbit and no black hole at all. This alternative scenario would require one of the stars to be 'stripped'. In other words, at earlier times it would have lost a large fraction of its mass to the other star.

> "*We had reached the limit of the existing data, so we had to turn to a different observational strategy to decide between the two scenarios proposed by the two teams*," said KU Leuven researcher Abigail Frost, who led the new study.

To solve the mystery, the two teams worked together to obtain new, sharper data of HR 6819 using ESO's Very Large Telescope (VLT) and Very Large Telescope Interferometer (VLTI). "*The VLTI was the only facility that would give us the decisive data we needed to distinguish between the two explanations*," said Dietrich Baade, Emeritus Scientist at ESO and author on both the original HR 6819 study and the new paper. Since it made no sense to ask for the same observation to be obtained twice, the two teams joined forces. That allowed them to pool their resources and knowledge to find the true nature of this system.

> "*The scenarios we were looking for were rather clear, very different and easily distinguishable with the right instrument*," says Rivinius. "*We agreed that there were two sources of light in the system, so the question was whether they orbit each other closely, as in the stripped-star scenario, or are far apart from each other, as in the black hole scenario*."

To distinguish between the two proposals, the astronomers used both the VLTI's GRAVITY instrument and the Multi Unit Spectroscopic Explorer (MUSE) instrument on the VLT.

> "*MUSE confirmed that there was no bright companion in a wider orbit, while GRAVITY's high spatial resolution was able to resolve two bright sources separated by only one-third of the distance between the Earth and the Sun*," said Frost. "*These data proved to be the final piece of the puzzle, and allowed us to conclude that HR 6819 is a binary* [stellar] *system with no black hole*."

> "*Our best interpretation so far is that we caught this binary system in a moment shortly after one of the stars had sucked the atmosphere off its* companion star. *This is a common phenomenon in close binary systems, sometimes referred to as 'stellar vampirism' in the press*," explains Bodensteiner, now a postdoctoral fellow at ESO. "*While the donor star was stripped of some of its material, the recipient star began to spin more rapidly*."

> "*Catching such a post-interaction phase is extremely difficult as it is so short*," adds Frost. "*This makes our findings for HR 6819 very exciting, as it presents a perfect candidate to study how this vampirism affects the evolution of massive stars, and in turn the formation of their associated phenomena including gravitational waves and violent supernova explosions*."

The newly formed joint team now plans to monitor HR 6819 more closely using the GRAVITY instrument. The researchers will conduct a joint study of the system over time, to better understand its evolution, constrain its properties, and use that knowledge to learn more about other binary systems and their potential to release gravitational waves.

As for the search for black holes, the teams remain optimistic.

> "*Stellar-mass black holes remain very elusive owing to their nature*," says Rivinius. "*But order-of-magnitude estimates suggest there are tens to hundreds of millions of* black holes *in the Milky Way alone*," Baade adds.

It is just a matter of time until astronomers discover them.

Better news on the black hole front emerged recently, in November 2021, when astronomers revealed the closest pair of *supermassive* black holes to Earth ever observed. The two objects also have a much smaller separation than any other previously spotted pair of supermassive black holes and will eventually merge into one giant black hole.

Karina Voggel of Strasbourg Observatory (France) and her team were able to determine the masses of the two objects by looking at how the gravitational pull of the black holes influences the motion of the stars around them. The bigger black hole, located right at the core of the galaxy NGC 7727, was found to have a mass of almost 154 million times that of the Sun, while its companion is 6.3 million solar masses.

This was the first time the individual masses had been measured in this way for a supermassive black hole pair. This feat was made possible thanks to the close proximity of the system to Earth and the detailed observations the team obtained at the Paranal Observatory in Chile—again using MUSE on the VLT. Measuring the masses with MUSE, and using additional data from the Hubble Space Telescope, allowed the team to confirm that the objects in NGC 7727 were indeed supermassive black holes.

Astronomers suspected that the galaxy hosted two black holes, rather than just one, but they had not been able to confirm their presence earlier. We do not observe large amounts of high-energy radiation coming from their immediate surroundings, which would otherwise have given them away.

> "*Our finding implies that there might be many more of these relics of galaxy mergers out there and they may contain many hidden* massive black holes *that still wait to be found*," said Voggel. "*It could increase the total number of* supermassive black holes *known in the local Universe by 30 percent*."

The search for similarly hidden supermassive black hole pairs is expected to make a great leap forward with the completion of the European Extremely Large

Telescope (ELT), which is set to start operating later this decade in Chile's Atacama Desert.

> "*This detection of a supermassive black hole pair is just the beginning*," said co-author Steffen Mieske, Head of ESO's Paranal Science Operations. "*With the HARMONI instrument on the ELT we will be able to make detections like this considerably further than currently possible. The ELT will be integral to understanding these objects*."

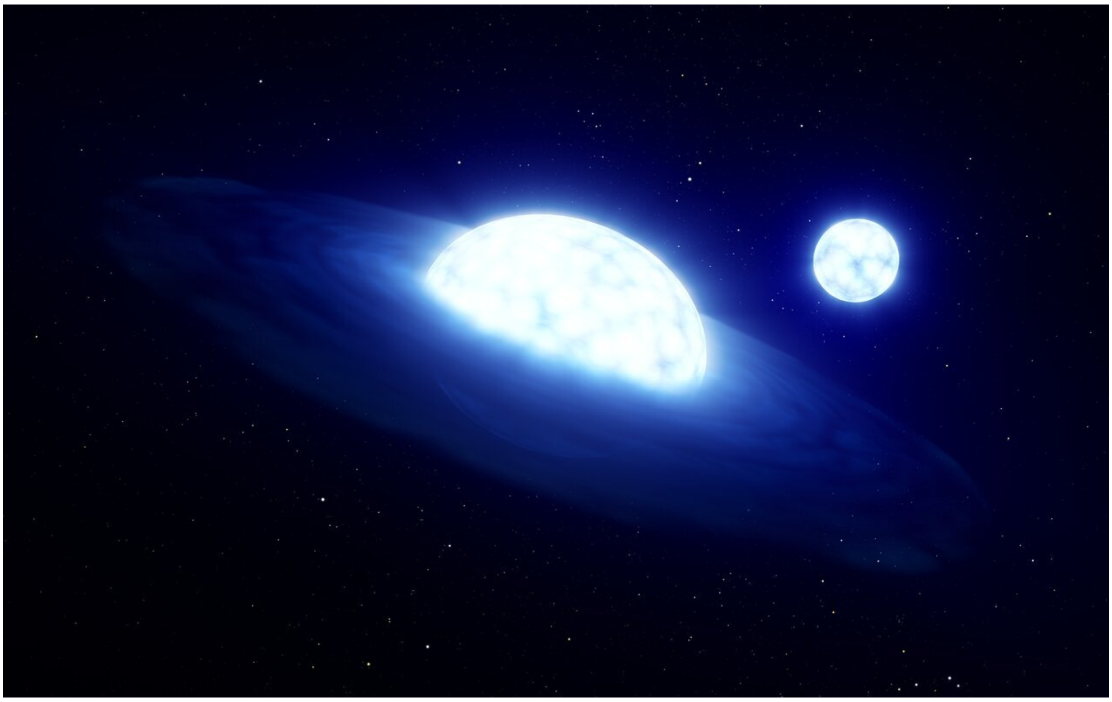

Figure 1. New research using data from ESO's Very Large Telescope and the Very Large Telescope Interferometer has revealed that HR 6819, previously believed to be a triple system with a black hole, is in fact a system of two stars with no black hole. This artist's impression shows what the system might look like; it is composed of an oblate star with a disk around it (a 'vampire' star; foreground) and a star that has been stripped of its atmosphere (background). (*Credit: ESO/L. Calçada*)

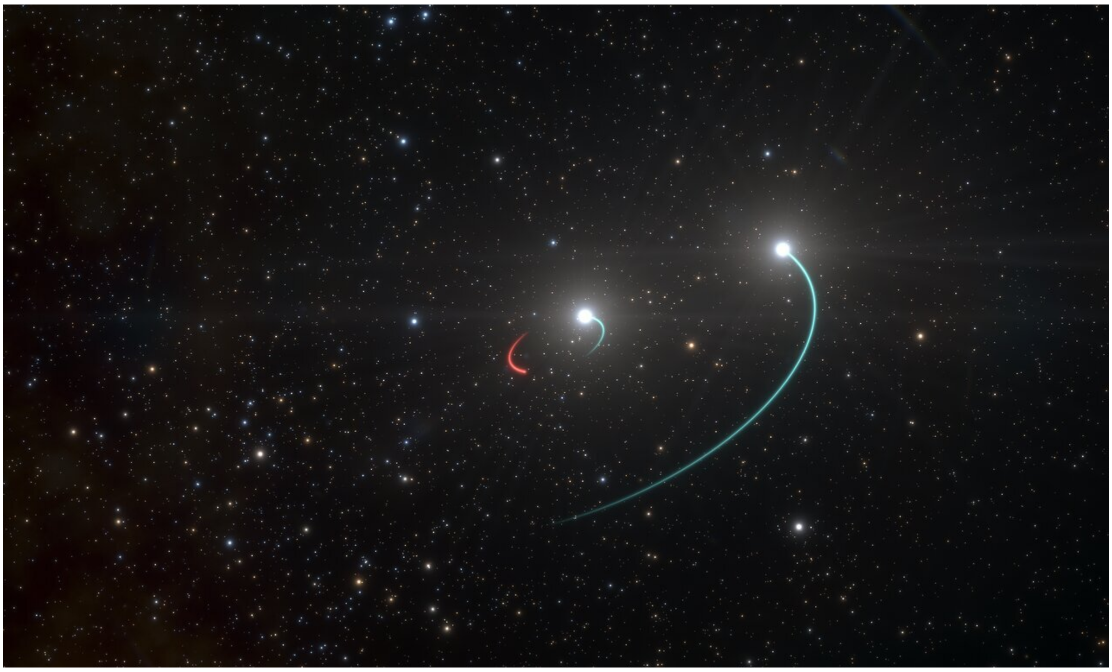

Figure 2. This artist's impression shows the orbits of the objects in the HR 6819 triple system. This system was originally thought to be made up of an inner binary with one star (orbit in blue) and a invisible object originally suspected to be a black hole (orbit in red), as well as a third star in a wider orbit (also in blue). The objects in the inner pair have roughly the same mass and circular orbits. (*Credit: ESO/L. Calçada*)

Figure 3. This image shows close-up (left) and wide (right) views of the two bright galactic nuclei, each housing a supermassive black hole, in NGC 7727, a galaxy located 89 million light-years away from Earth in the constellation Aquarius. Each nucleus consists of a dense group of stars with a supermassive black hole at its centre. The two black holes are on a collision course and form the closest pair of supermassive black holes found to date. It is also the pair with the smallest separation between two supermassive black holes found to date — observed to be just 1,600 light-years apart in the sky. The image on the left was taken with the MUSE instrument on the VLT, while the one on the right was taken with ESO's VLT Survey Telescope. (*Credit: ESO/Voggel et al.; ESO/VST ATLAS team. Acknowledgement: Durham University/CASU/WFAU*)

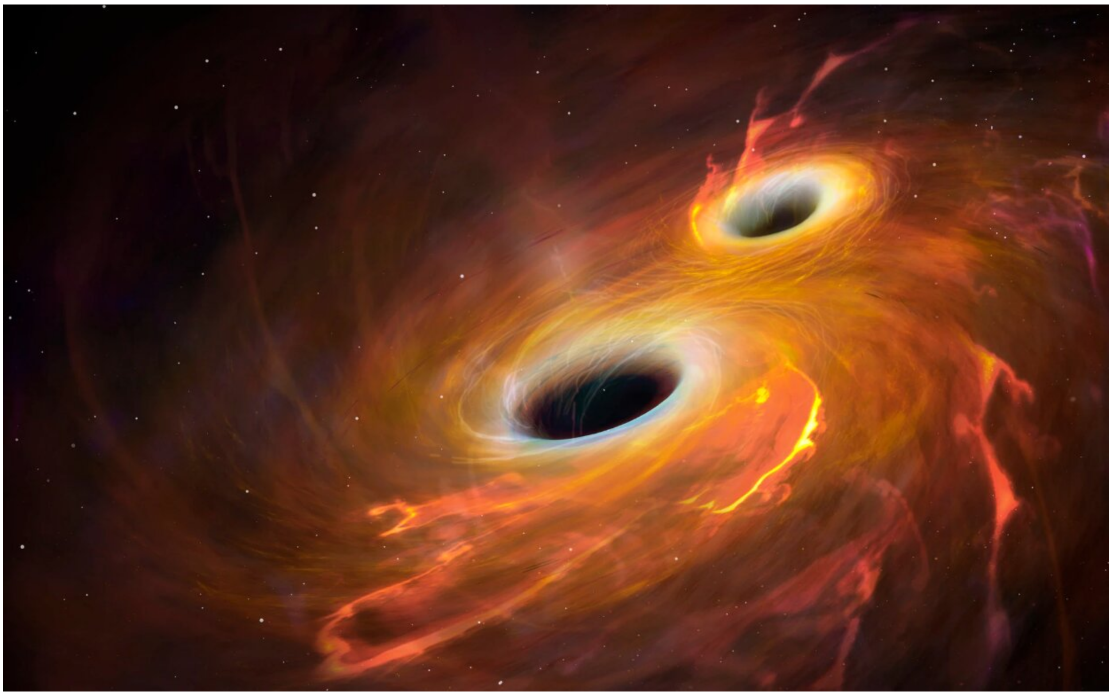

Figure 4. Artist's impression of two black holes about to collide and merge. (Credit: Mark Garlick)