How massive is Supermassive? Astronomers measure more black holes, farther away

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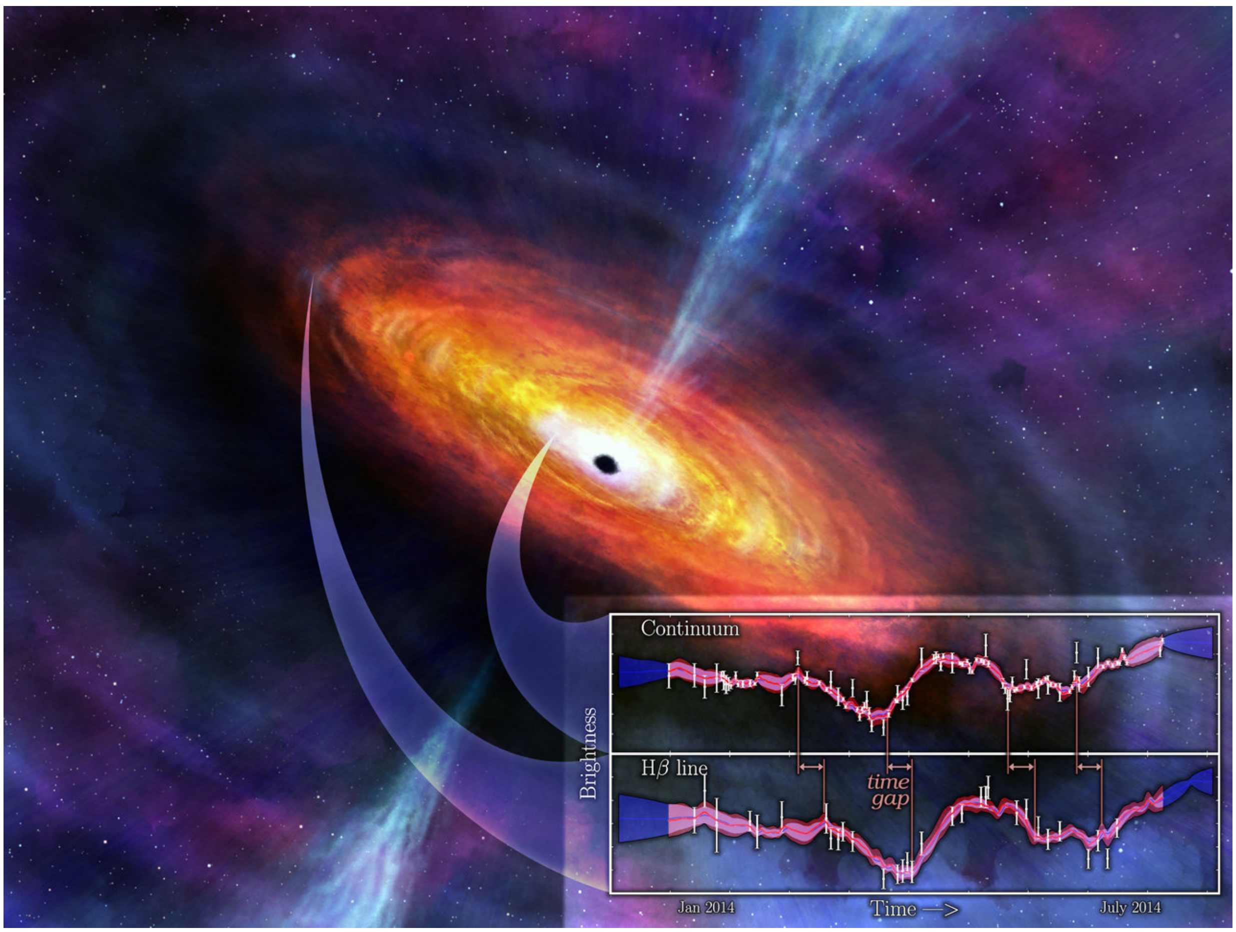


An artist's rendering of the inner regions of an active galaxy/quasar, with a supermassive black hole at the center surrounded by a disk of hot material falling in. The inset at the bottom right shows how the brightness of light coming from the two different regions changes with time. The top panel of the plot shows the "continuum" region, which originates close in to the black hole (the general vicinity is indicated by the "swoosh" shape). The bottom panel shows the H-beta emission line region, which comes from fast-moving hydrogen gas farther away from the black hole (the general vicinity is indicated by the other “swoosh”). The time span covered by these two light curves is about six months. The bottom plot “echoes” the top, with a slight time delay of about 10 days indicated by the vertical line. This means that the distance between these two regions is about 10 light-days (about 150 billion miles, or 240 million kilometers). Credit: Nahks Tr’Ehnl (www.nahks.com) and Catherine Grier (The Pennsylvania State University) and the SDSS collaboration

Today, astronomers from the Sloan Digital Sky Survey (SDSS) announced new measurements of the masses of a large sample of supermassive black holes far beyond the local Universe.

The results, being presented at the American Astronomical Society (AAS) meeting in National Harbor, Maryland and published in the *Astrophysical Journal*, represent a major step forward in our ability to measure supermassive black hole masses in large numbers of distant quasars and galaxies.

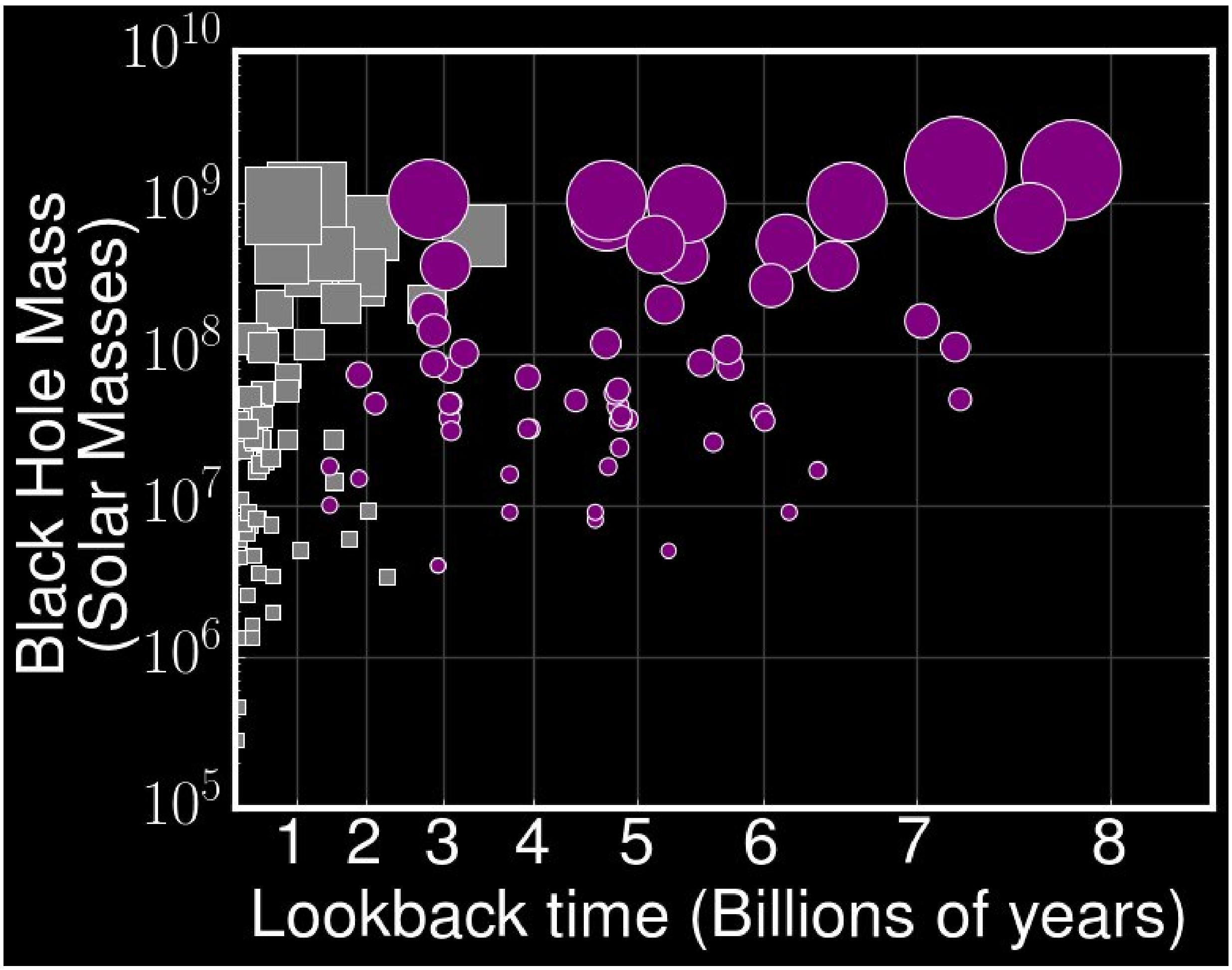
"This is the first time that we have directly measured masses for so many supermassive black holes so far away," says Catherine Grier, a postdoctoral fellow at the Pennsylvania State University and the lead author of this work. "These new measurements, and future measurements like them, will provide vital information for people studying how galaxies grow and evolve throughout cosmic time."

Supermassive black holes (SMBHs) are found in the centers of nearly every large galaxy, including those in the farthest reaches of the Universe. The gravitational attraction of these supermassive black holes is so great that nearby dust and gas in the host galaxy is inexorably drawn in. The infalling material heats up to such high temperatures that it glows brightly enough to be seen all the way across the Universe. These bright disks of hot gas are known as "quasars," and they are clear indicators of the presence of supermassive black holes. By studying these quasars, we learn not only about SMBHs, but also about the distant galaxies that they live in. But to do all of this requires measurements of the properties of the SMBHs, most importantly their masses.

The problem is that measuring the masses of SMBHs is a daunting task. Astronomers measure SMBH masses in nearby galaxies by observing groups of stars and gas near the galaxy center—however, these techniques do not work for more distant galaxies, because they are so far away that telescopes cannot resolve their centers. Direct SMBH mass measurements in galaxies farther away are made using a technique called "reverberation mapping."

Reverberation mapping works by comparing the brightness of light coming from gas very close in to the black hole (referred to as the "continuum" light) to the brightness of light coming from fast-moving gas farther out. Changes occurring in the continuum region impact the outer region, but light takes time to travel outwards, or "reverberate." This reverberation means that there is a time delay between the variations seen in the two regions. By measuring this time delay, astronomers can determine how far out the gas is from the black hole. Knowing that distance allows them to measure the mass of the supermassive black hole—even though they can't see the details of the black hole itself.

Over the past 20 years, astronomers have used the reverberation mapping technique to laboriously measure the masses of around 60 SMBHs in nearby active galaxies. Reverberation mapping requires getting observations of these active galaxies, over and over again for several months—and so for the most part, measurements are made for only a handful of active galaxies at a time. Using the reverberation mapping technique on quasars, which are farther away, is even more difficult, requiring years of repeated observations. Because of these observational difficulties, astronomers had only successfully used reverberation mapping to measure SMBH masses for a handful of more distant quasars—until now.



A graph of known supermassive black hole masses at various "lookback times," which measures the time into the past we see when we look at each quasar. More distant quasars have longer lookback times (since their light takes longer to travel to Earth), so we see them as they appeared in the more distant past. The Universe is about 13.8 billion years old, so the graph goes back to when the Universe was about half of its current age. The black hole masses measured in this work are shown as purple circles, while gray squares show black hole masses measured by prior reverberation mapping projects. The sizes of the squares and circles are related to the masses of the black holes they represent. The graph shows black holes from 5 million to 1.7 billion times the mass of the sun. Credit: Catherine Grier (The Pennsylvania State University) and the SDSS collaboration

In this new work, Grier's team has used an industrial-scale application of the reverberation mapping technique with the goal of measuring black hole masses in tens to hundreds of quasars. The key to the success of the SDSS Reverberation Mapping project lies in the SDSS's ability to study many quasars at once—the program is currently observing about 850 quasars simultaneously. But even with the SDSS's powerful telescope, this is a challenging task because these distant quasars are incredibly faint.

"You have to calibrate these measurements very carefully to make sure you really understand what the quasar system is doing," says Jon Trump, an assistant professor at the University of Connecticut and a member of the research team.

Improvements in the calibrations were obtained by also observing the quasars with the Canada-France-Hawaii-Telescope (CFHT) and the Steward Observatory Bok telescope located at Kitt Peak over the same observing season. After all of the observations were compiled and the calibration process was completed, the team found reverberation time delays for 44 quasars. They used these time delay measurements to calculate black hole masses that range from about 5 million to 1.7 billion times the mass of our sun.

"This is a big step forward for quasar science," says Aaron Barth, a professor of astronomy at the University of California, Irvine who was not involved in the team's research. "They have shown for the first time that these difficult measurements can be done in mass-production mode."

These new SDSS measurements increase the total number of active galaxies with SMBH mass measurements by about two-thirds, and push the measurements farther back in time to when the Universe was only half of its current age. But the team isn't stopping there—they continue to observe these 850 quasars with SDSS, and the additional years of data will allow them to measure black hole masses in even more distant quasars, which have longer time delays that cannot be measured with a single year of data.

"Getting observations of quasars over multiple years is crucial to obtain good measurements," says Yue Shen, an assistant professor at the University of Illinois and Principal Investigator of the SDSS Reverberation Mapping project. "As we continue our project to monitor more and more quasars for years to come, we will be able to better understand how supermassive black holes grow and evolve."

The future of the SDSS holds many more exciting possibilities for using reverberation mapping to measure masses of supermassive black holes across the Universe. After the current fourth phase of the SDSS ends in 2020, the fifth phase of the program, SDSS-V, begins. SDSS-V features a new program called the Black Hole Mapper, which plans to measure SMBH masses in more than 1,000 more quasars, pushing farther out into the Universe than any reverberation mapping project ever before.

"The Black Hole Mapper will let us move into the age of supermassive black hole reverberation mapping on a true industrial scale," says Niel Brandt, a professor of Astronomy & Astrophysics at the Pennsylvania State University and a long-time member of the SDSS. "We will learn more about these mysterious objects than ever before."

More information: C. J. Grier et al. The Sloan Digital Sky Survey Reverberation Mapping Project: Hα and Hβ Reverberation Measurements from First-year Spectroscopy and Photometry, *The Astrophysical Journal* (2017). DOI: 10.3847/1538-4357/aa98dc

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