The first supermassive black holes

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The next generation x-ray telescope XEUS (x-ray evolving-universe spectroscopy) will be sensitive enough to detect the first generation of supermassive black holes and to study their growth.

Scientists are currently in a golden age of astrophysics where several fundamental discoveries have led to paradigm shifts in recent years. One of those discoveries was the realization that supermassive black holes are essential elements to the formation of galaxies and play important roles in their evolution. Black holes are found at the centers of all larger galaxies, including the Milky Way. They reveal themselves by the gravitational action on their surrounding stars and gases. There is a strong correlation between the mass of the central black hole and the properties of its host galaxy; for example, the mass and velocity dispersion of its central spheroidal bulge.

There is also an interesting similarity between the growth history of black holes and the formation history of stars in the universe. These histories suggest an intimate relationship between the formation and evolution of galaxies and black holes.7 In addition, it was realized only recently that black hole growth has

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The space density of optically-selected QSOs as a function of redshift is given by the set of dark-red triangles.4–6 The x-ray and optical data were scaled vertically to match the radio determination of space density at redshifts from 2.0 to 2.5. (Right) An artist’s concept of the XEUS mission is illustrated.
an important impact on the evolution of massive galaxies. Such an impact is caused by the energetic feedback from the accretion (the accumulation of mass by the black hole), which can substantially alter the appearance of a galaxy: in particular, by blowing away free gases and shutting off star formation.\(^8\)

The first stars and galaxies formed where gravity overpowered the pressure of the ambient baryons. Ultimately, gravity dominated the process, resulting in the formation of the first stellar mass black holes: likely in gamma-ray burst explosions. Thus, supermassive black holes probably grow from stellar seeds by cataclysmic feeding events during major starburst episodes.\(^9\) The highest known redshift-accreting black holes and galaxies have values of \(z\) around 6.5, where \(z\) is the function of the Doppler shift. The first light that appeared, however, must have started to ionize the universe already as early as \(z\) equals 10. This implies that supermassive black holes are an important constituent of the evolving universe.

X-ray astronomy is a crucial element of modern astrophysics and is particularly well suited for studying matter under extreme conditions, like that around black holes. The cosmic x-ray background has been resolved into discrete sources, mostly accreting black holes, of which the most distant are at values of \(z\) greater than 5. However, the sample sizes at large redshifts are still sparse. Current information comparing the space density and growth of supermassive black holes in the early universe, based on multi-wavelength radio, optical, and x-ray data, is shown in Figure 1 (left). The study of the birth and growth of supermassive black holes at \(z\) approximately equal to 10 requires an unprecedented combination of large spectral throughput, a high angular resolving power, and a large field of view in the x-ray regime matching those of future optical and radio telescopes.

The mission requires that XEUS detect and study x-ray-emitting black holes out to \(z\) equals 10 and to investigate their nature. By the time XEUS is launched (planned no earlier than 2017), cosmologists should know about many more objects at high redshifts due to the large-scale x-ray and infrared surveys planned for the near future. To study the overall properties of such objects, their spectral energy distribution, the amount of absorption, and the properties of any Fe (iron) lines need to be measured. This latter topic—the study of Fe lines from distant x-ray sources—is one of the key XEUS goals. This is because the line energy provides the redshift (which allows the object’s luminosity and distance to be determined), along with information about the spin of the black hole and the chemical abundance of the accreted material. For the less luminous objects, James Webb Space Telescope (JWST) and Atacama Large Millimeter Array (ALMA) observations will be needed to determine redshifts.

The current XEUS configuration uses a separate mirror and detector spacecraft with a single Ariane 5 launch to a second Lagrange point (L2) orbit: see Figure 1 (right). The telescope is equipped with a single, non-deployable mirror made from high-precision silicon pore optics, and provides an effective area of nearly 6\(m^2\) at 1keV and more than 2\(m^2\) at 7keV with a focal length of 35m. The angular resolution (HEW, or half energy width) goal is two arcseconds (\(2^\prime\)), with 5\(^\prime\) required. The current baseline payload consists of a single cryogenic imaging high-resolution spectrometer and a wide-field-of-view imager with CCD-type energy resolution. A hard x-ray telescope employing multilayers, a high-time-resolution spectrometer, and, possibly, an x-ray polarimeter, are being considered as well.

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**References**