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Physicists produce black hole plasma in the lab

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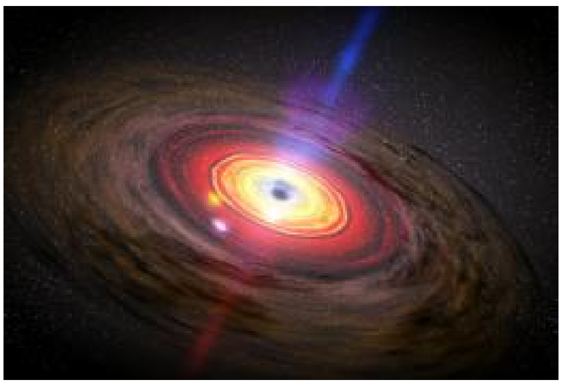


Exotic structure: There is a lot of turbulence in the vicinity of a black hole. What exactly is happening there? Image: NASA/Dana Berry, SkyWorks Digital

(PhysOrg.com) -- Black holes are voracious: They devour large amounts of matter from gas clouds or stars in their neighbourhood. As the incoming "food" spirals faster and faster into the abyss, it becomes denser and denser, and heats up to temperatures of many millions of degrees Celsius. Before the matter finally disappears, it emits extraordinarily intense X-rays into space. This "last cry" originates from iron, one of the elements contained in this matter. Researchers at the Max Planck Institute for Nuclear Physics in Heidelberg have collaborated with colleagues at the Helmholtz Zentrum Berlin and used the BESSY II synchrotron X-ray source to investigate what happens in this process.

In order to understand the nature of black holes, it is best to watch them feeding. The most interesting part is just before the matter disappears behind the event horizon - that is, the distance at which the mass attraction of the black hole becomes so strong that not even light can escape. This turbulent process generates X-rays, which in turn excite various chemical elements in the cloud of matter to emit X-rays themselves with characteristic lines ("colours"). An analysis of the lines provides information on the density, velocity and composition of the plasmas near the event horizon.

During this process iron plays an important role. Although it is not as abundant in the universe as lighter elements - mainly hydrogen and helium - it is much better at absorbing and reemitting X-rays. The photons emitted thereby also have a higher energy, respectively a shorter wavelength (a different "colour"), than that of the lighter atoms.

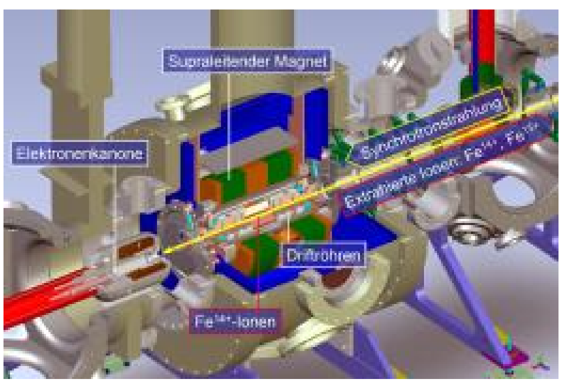
They therefore leave behind clear fingerprints in the rainbow of the dispersed radiation: in the spectrum they reveal themselves as strong lines. The so-called K-alpha line of iron is the final visible spectral signature of matter, its "last cry", before it disappears behind the event horizon of a black hole, never to be seen again.

The X-rays emitted are also absorbed as they pass through the medium surrounding the black hole at larger distances. And here iron again leaves behind clear fingerprints in the spectra. The radiation ionises the atoms several times and so-called photoionisation typically strips away more than half of the 26 electrons which the iron atoms usually contain. This produces ions with positive charge states that correspond to the number of stripped electrons. The end result is highly charged ions produced not by collisions but by radiation.

It is precisely this process, the stripping of further electrons from highly charged ions by incident X-rays, which researchers at the Max Planck

Institute for Nuclear Physics have reproduced in the laboratory in collaboration with colleagues at BESSY II - the Berlin synchrotron X-ray source. The heart of the experiment was the EBIT electron beam ion trap designed at the Max-Planck institute. Inside the trap, iron atoms were heated up with the aid of an intense electron beam as they would be deep inside the sun or, as in this case, in the vicinity of a black hole.

Under such conditions, iron exists, for example, as the Fe^{14+} ion, ionised fourteen times as it were. The experiment proceeds as follows: A cloud of these ions, only a few centimetres long and thin as a hair, is kept suspended in an ultra-high vacuum with the help of magnetic and electric fields. X-rays from the synchrotron then impact on this cloud; the photon energy of the X-rays is selected by a "monochromator" with extreme precision and directed onto the ions as a thin, focused beam.



The researchers use EBIT, the electron beam ion trap, to reconstruct processes in the laboratory as they occur in the matter around black holes. Image: MPI for Nuclear Physics

The spectral lines measured in this experiment can be directly and easily compared with the most recent observations made by X-ray observatories, like Chandra and XMM-Newton. It turns out that most of the theoretical calculation methods used do not predict the line positions accurately enough. This is a big problem for the astrophysicists, because without accurate knowledge of the wavelengths there is no accurate determination of the so-called Doppler effect of these lines.

The Doppler effect describes the change in frequency (energy or wavelength) of the emitted light as a function of the velocity of the source (the ions in the plasma.). Anyone who listens to the siren of a passing ambulance experiences this phenomenon: as long as the vehicle approaches, the perceived pitch of the sound is higher; as it moves away, it is lower. If the frequency in the system at rest is known (ambulance is stationary), measuring the pitch makes it possible to determine the velocity of the source - in astronomy this is the plasma.

This left the scientists puzzled over the interpretation of NGC 3783, one of the active galactic nuclei which have been under investigation for the longest time. The error bars in the frequency in a rest frame calculated with the aid of different theoretical models led to such large uncertainties in the derived velocity of the emitting plasma that reliable statements on the plasma flows were no longer possible.

The laboratory measurements of the Heidelberg-based Max-Planck researchers have now identified one theoretical method among several model calculations that provides the most accurate predictions. They also achieved the highest spectral resolution to date in this wavelength range. It had previously not been possible to experimentally check the different theories in this energy range with such high accuracy.

The novel combination of a trap for highly charged ions and bright synchrotron radiation sources thus represents an important step and a new approach for understanding the physics in the plasmas around black holes or active galactic nuclei. The researchers expect the combination of EBIT spectroscopy and brighter and brighter X-ray sources of the third (PETRA III at DESY) and fourth generation (free-electron laser XFEL, Hamburg/Germany; LCLS, Stanford, USA; SCSS, Tsukuba, Japan) to bring fresh drive to this field.

More information: *Physical Review Letters*, Vol. 105, p. 183001, October 29, 2010. The article in Physical Review Letters - link.aps.org/doi/10.1103/PhysRevLett.105.183001

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