# Cold Atoms Identified as Inflows Fueling Quasar Black Hole Accretion Disks

By SONG Jianlan (Staff Reporter)

*A group of scientists reported in Nature their latest discovery of a large amount of hydrogen and helium gases on the outer brim of the accretion disks surrounding the central supermassive black holes in a sample of quasars. Their strongly redshifted and broadened absorption lines indicate that they are moving at freefall-like speeds and hence deemed prey of the mighty gravitation of the supermassive black holes.*

*This marked the first ever observational evidence of inflows fueling the accretion disks, and thought to be fixing the last puzzle of the quasar black hole accretion model – the most successful theory so far to explain the energy source of quasars, a mysterious type of celestial bodies.*

Quasars have remained mysterious for astronomers. Particularly, their complicated, bright radiations are hard to understand. Shown is an artist's impression of ULAS J1120+0641, the most distant quasar found so far, illustrating how it might have looked just 770 million years after the Big Bang. In the early cosmos, it was by far the brightest object yet discovered by human beings. [Credit: ESO/M. Kornmesser, CC BY 4.0 (https://creativecommons.org/licenses/by/4.0); Source: https://www.eso.org/public/images/eso1122a/]

On September 5, an international team of scientists reported in *Nature* their detection of redshifted broad absorption lines left behind by hydrogen and helium atoms adjacent to the accretion disks of a group of quasars. These broad troughs indicate that these gases, at a yearly consumption rate of several dozen solar masses, are moving inward at velocities comparable to freefall speeds towards the accretion disks, articulated the coauthors. The team is comprised of researchers from the Polar Research Institute of China (PRIC), the University of Science and Technology of China (USTC) and the National Astronomical Observatories of China (NAOC), Chinese Academy of Sciences (CAS) and other institutions. Offering the first ever unambiguous observational evidence of inflows fueling the accretion disks surrounding central black holes of quasars, this long-awaited discovery is believed to have identified "the last puzzle" of the black hole accretion model, the most successful theory so far explaining the energy source of quasars, a mysterious existence in the cosmos.

## Weird "Stars"

Since they came to light in the 1960s, quasars (short for "quasi-stellar radio objects") have been elusive to astronomers. They appear very dim, weak and tiny in telescopes, just like the most obscure stars – if one is lucky enough to find them, but their intensive high-energy radiations suggest a great amount of energy coming from nowhere, and the high redshift in their emission spectra resisted explanation in a time when the concept of "black hole" was no more than a myth. Yes, such high extent of redshifts could be produced by an object escaping fast enough from the Earth – at a speed equivalent to fractions of the speed of light, which unfortunately would be impossible. Otherwise, however, such strong redshifts would have to mean very large cosmic distances, and hence extremely bright intrinsic luminosities – again, this demands a tremendous amount of energy that defies imagination.

Astronomers did not arrive at agreement on the nature of quasars until the 1970s, after continuous observations, theoretical explorations and debates. They came to realize that such star-like dots are actually galaxies with active supermassive black holes at their hearts, or active galaxy nuclei (AGNs); and exactly it is the central black holes that have powered them with the huge amount of energy.

Due to their mighty gravity, the central black holes can suck up any object in their reach. While falling onto the central black holes, the victim object gains momenta in the gravitational field, and hence be accelerated, until it reaches a speed near to that of light. On the way, the object breaks down; the fragments moving at different speeds bump with each other and get heated, decomposed and ionized, losing their original matter state. Eventually they are reduced to flows of plasma matter and form a disk surrounding the central supermassive black hole, emitting a great amount of optical, ultraviolet, and X-ray radiations. Struggling in the strong gravitational field of the black hole, their potential energy transforms into a great amount of kinetic energy; moreover, 4~42% of their mass can be converted into energy in this process called "accretion", much higher than the rate 0.7% for nuclear fusion reaction, which dominates the energy production process in Sun-like stars as we know. The remains of the fueling mass ultimately arrive at the black hole horizon and get devoured by the supermassive monster.

The above process is just the scenario given by a theory called "black hole accretion", which has successfully explained many phenomena observed on quasars, including their tremendous energy, and hence evolved into the "standard model" for quasars and AGNs today.

## "The Last Puzzle" of Black Hole Accretion

This "standard model", however, is not complete yet. One "component" is still missing.

Astronomers believe that a large amount of mass could be pulled at the central black hole, to fuel the accretion disk with matter and energy. Such inflows that directly fall onto and actually arrive at the accretion disc, however, had never been observed. Though some observational evidence had been obtained indicating such inflows toward the center at the galactic or circumnuclear scales, the observed matter in those areas is still very far away – over several hundred light years – from the central black hole. Given the small radial momenta and relatively much larger circular velocities of the matter in these areas, it is very hard to determine whether the matter can really approach and actually arrive at the accretion disk and finally the central black hole, which both appear extremely tiny for observers on the Earth.

The extremely tiny apparent size makes it very challenging to directly observe the nuclear part of a quasar, not to mention distinguishing the inflows and the accretion disk. "Quasars are very far from us," said Prof.

ZHOU Hongyan, a professor at PRIC and USTC, first and joint corresponding author of the *Nature* paper. "They appear like just some point sources, and hence very hard to differentiate their different parts and compositions," he explained. "To understand the movement and distribution of the gases adjacent to the nucleus, a traditional way is to measure the emission lines of the gases' atoms or ions. But when what you get is a sum of all these lines from all directions, it would be difficult to determine how the gases are actually moving."

Therefore, it would be hard to tell from the emission lines whether the matter emitting them is falling onto the accretion disk or not; nor can we know how it falls onto the disk.

Seems it is a dead-end.

### Markers for Inflows

The joint team turned to the absorption lines in quasars' spectra for an answer. They sought to find signs from hydrogen and helium atoms that are not yet ionized – if they do exist, they would leave characteristic dark troughs on the spectrum. Following these troughs, the trajectory of their movement could be reconstructed.

This strategy, however, was once thought impossible.

"At first people did not expect that it could be so 'cold' on the outer brim of the disk that any atom could survive," said Prof. YUAN Weimin, ZHOU's cooperator at NAOC, and joint corresponding author of the *Nature* paper. "Generally, people presumed that hydrogen and helium atoms would have been ionized before arriving there and become plasma," he continued, "hence they would not leave any recognizable pattern of absorption lines."

Their modelling told a different story. Their calculation indicated, there should exist some gas atoms on the outer brim of the accretion disk. The temperatures there are relatively lower, radiations weaker, hence some atoms might be able to survive the ionization. Retaining the state of atoms, they can leave their own "fingerprints" – signature patterns of absorption lines repeatedly spreading across the quasar spectra. The lines, or the dark troughs, are "etched" down by the electrons travelling on the outer orbits of the atoms. When the intensive, shiny radiations from the accretion disk transmit to the outer space and bombard the atoms, the electrons of the latter can absorb certain units (quanta) of energy and transit to higher orbits.

An artist's interpretation of black hole accretion: The black hole behaves like a devastating dragon, which gobbles up anything falling within the influence of its breath. (Image by CUI Jie, USTC)

This absorption leaves "notches" at certain frequencies on the otherwise continuous spectra, which form fixed patterns of spectral lines against the bright radiations emitted by the plasma accretion disk, betraying the existence of atoms. These signature patterns can serve as markers of the inflows, showing the trajectory of the latter – if the atoms happen to be flying inwards along our line of sight to approach the accretion disk, the spectral troughs they notch on the spectra would be widened by redshifts to lower frequencies, a phenomenon caused by Doppler effect.

All this said, the redshifted and widened troughs, or the absorption lines on the spectra, might not be visible from the Earth. The gases can fly in any direction to arrive at the central black hole, only those flying fast away from us along our line of sight towards the accretion disk will produce the absorption lines; among them, some could further be overshadowed by interstellar matter that happens to get in the way. Thankfully, slim as the chances are, still can we observe such redshifted broad absorption lines at some possibility.

The team's modelling predicted right – their survey in a sample of approximately 100,000 quasars detected in eight quasars pure redshifted broad absorption lines of both hydrogen and helium series. Eventually, they obtained the first straightforward observational evidence for inflows fueling the accretion disk.

"These absorption lines redshifted to longer wavelengths," said ZHOU, "demonstrate that the gases producing the absorption are fast moving toward the central black hole. This distinguishes them with the interstellar matter irrelevant to the accretion."

"These redshifts correspond to the radial velocities of these atoms toward the central black hole, rather than the circular speed," added YUAN. The team's analysis indicates that the redshifts extend continuously across a speed range from zero to 5,000 km per second. The only explanation, the coauthors noted, would be these gases are travelling toward the central black hole at velocities comparable to freefall speeds. As indicated by a comparison between their theoretical calculation and the properties of the observed absorption lines, these gases are located beyond but adjacent to the accretion disk. Given their centripetal velocities comparable to freefall speeds and the formidable gravity of the black hole, these gases would have no way to go other than falling onto the accretion disk and finally the black hole.

Seems that the last puzzle for the black hole accretion of quasars has been captured. Nevertheless, the "ultimate question" about quasars and the black hole accretion, however, remains unsolved, the researchers cautioned.

## "Ultimate Question"

Previous observations found that quasars are instable – their luminosity for example, keeps varying. This might have something to do with the mass fueling onto the accretion disk. Judging from this, scientists reckon the energy supply of quasars might not be sustainable: once the matter within the reach of the black hole burns out, the accretion might stop and the galaxy goes into a quiescent stage.

The black hole at the center of the Milky Way in which we dwell, for example, is quiescent. Therefore, scientists speculate that each galaxy might have a central black hole, and all of them have experienced some radical accretion. The difference is, some went into quiescence after consuming all reachable matter, while some are still on the way. At some certain situations, the latent black holes could be reignited, and the accretion reactivated. Exactly at what situations, via what mechanisms could a quiescent galaxy be reawakened, are still unknown.

"In a quiescent galaxy, the circling matter maintains some subtle balance with the central black hole. The matter circling the central black hole at a certain distance possesses some angular momenta, which help it counteract the black hole's gravity and protects it from falling. Once it has lost enough angular momentum, its fate would be changed. Under what conditions this will happen, we do not know yet," said YUAN. "Therefore, our discovery does not thoroughly solve the problem. It has just opened a new window onto the study of supermassive black holes, through which astronomers can further examine how they trigger an accretion, and how they grow and evolve."

### Reference

**Hongyan Zhou***, Xiheng Shi, **Weimin Yuan***, Lei Hao, Xiangjun Chen, Jian Ge, Tuo Ji, Peng Jiang, Ge Li, Bifang Liu, Guilin Liu, Wenjuan Liu, Honglin Lu, Xiang Pan, Juntai Shen, Xinwen Shu, Luming Sun, Qiguo Tian, Huiyuan Wang, **Tinggui Wang***, Shengmiao Wu, Chenwei Yang, Shaohua Zhang & Zhihao Zhong. (2019) Fast inflows as the adjacent fuel of supermassive black hole accretion disks in quasars. *Nature*, 573: 83–86.