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THE FORMATION OF SUPERMASSIVE BLACK HOLES AND THEIR INFLUENCE ON GALAXY EVOLUTION

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Abstract
This review examines how supermassive black holes form and how they influence the evolution of their host galaxies. It describes two possible origins for the black holes that later grow into these massive objects. Some may form from the remnants of the first massive stars, while others may arise when large clouds of gas collapse under their own gravity. These initial black holes can grow by accreting gas and merging with other black holes. As gas falls toward a central black hole, it can release energy through radiation and generate winds or jets. These processes can heat or displace the gas from which new stars form, changing the rate of star formation. The review also explains how the supply of gas in a galaxy affects the growth of its central black hole. Together, these processes illustrate how supermassive black holes and their host galaxies evolve in response to each other. NASA Science.

Keywords: Supermassive black holes, black hole seeds, gas accretion, black hole mergers, active galactic nuclei, star formation, galaxy evolution.

Introduction

Annotatsiya
Ushbu sharhda o‘ta katta massali qora tuynuklarning qanday shakllanishi va ular o‘zlari joylashgan galaktikalarning evolyutsiyasiga qanday ta’sir ko‘rsatishi yoritiladi. Keyinchalik o‘ta katta massaga ega bo‘ladigan qora tuynuklarning paydo bo‘lishi uchun ikkita ehtimoliy yo‘l ko‘rib chiqiladi. Ularning ayrimlari dastlabki katta massali yulduzlarning qoldiqlaridan, boshqalari esa yirik gaz bulutlarining o‘z tortishish kuchi ta’sirida siqilishi natijasida hosil bo‘lishi mumkin. Bu boshlang‘ich qora tuynuklar gazni yutish va boshqa qora tuynuklar bilan qo‘shilish orqali o‘sadi. Gaz markaziy qora tuynuk tomon oqib borar ekan, nurlanish shaklida energiya ajralishi, kuchli shamollar yoki yo‘naltirilgan oqimlar paydo bo‘lishi mumkin. Bu jarayonlar yangi yulduzlar hosil bo‘ladigan gazni qizdirishi yoki uning joylashuvini o‘zgartirishi natijasida yulduzlar shakllanishi sur’atiga ta’sir qiladi. Sharhda galaktikadagi gaz zaxirasi markaziy qora tuynukning o‘sishiga qanday ta’sir qilishi ham tushuntiriladi. Ushbu jarayonlar o‘ta katta massali qora tuynuklar va ular joylashgan galaktikalar o‘zaro ta’sirda rivojlanishini ko‘rsatadi. NASA Science

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Kalit so‘zlar. O‘ta katta massali qora tuynuklar, boshlang‘ich qora tuynuklar, gaz akkretsiyasi, qora tuynuklarning qo‘shilishi, faol galaktika yadrolari, yulduzlarning shakllanishi, galaktikalar evolyutsiyasi.

Introduction

Supermassive black holes are found at the centers of many galaxies. Their formation is closely connected to the history of the universe because some had already reached enormous masses when the earliest galaxies were still developing. To explain this rapid growth, astronomers study the smaller black holes, called seeds, from which these objects may have formed. Two possible origins are the collapse of the first massive stars and the direct collapse of large gas clouds. Once formed, a seed can grow by drawing in surrounding gas or by merging with another black hole.

This relationship works in both directions. Gas in a galaxy can feed its central black hole. As it flows inward, it can release energy as radiation and drive powerful winds or jets. These processes can heat surrounding gas or push it away from regions where stars form. Because new stars form when gas cools and collapses under gravity, such changes can affect how quickly a galaxy forms stars. Astronomers call this exchange of energy between an active galactic nucleus and its surroundings feedback.

This article examines the proposed origins of black hole seeds, the processes that allow them to grow, and the ways in which their activity changes the gas within galaxies. It connects these mechanisms to observations of early galaxies and their bright nuclei, known as quasars.

Methods

This article uses a comparative literature review to examine how supermassive black holes form and how their activity influences galaxies. The review draws on research articles, scientific reviews, and materials from astronomical observatories. Sources were selected for their relevance to three questions. How might the first black holes have formed? What processes could have increased their masses? How can the activity near a central black hole change the gas available for star formation? The analysis followed this sequence so that the origin of black holes, their growth, and their effects on galaxies could be considered as connected processes.

The first stage compared two proposed pathways for the formation of black hole seeds. The stellar remnant pathway begins with the collapse of a massive star. The direct collapse pathway begins with a large concentration of gas that collapses under its own gravity and can produce a heavier seed. For each pathway, the review considered the initial mass of the seed, the conditions of its surroundings, and the amount of growth needed to reach a supermassive scale. Observations of distant quasars provided a common point of comparison. The estimated masses of their central black holes were considered alongside the time available for growth at the epoch when the quasars were observed.

The second stage examined growth through gas accretion and black hole mergers. For accretion, the comparison focused on the supply of gas, the rate at which matter could reach the black hole, and the duration of active growth. The discussion of mergers followed the sequence from the interaction of two galaxies to the possible formation and eventual merger of

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a black hole pair. These processes were considered together because a black hole may gain mass by accretion during several periods of activity and also grow through mergers over the course of its history.

The third stage examined how energy released near a growing black hole can affect its host galaxy. The evidence was organized by the mechanism involved, including radiation, winds, and jets. Each mechanism was traced from its source near the black hole to its possible effects on the surrounding gas. The comparison considered whether the gas was heated, compressed, or displaced and how each change could influence the formation of stars. Observations at different wavelengths were used to follow distinct parts of this process. Radio observations can reveal jets, X-ray observations can reveal hot gas, and observations at millimeter wavelengths can trace cold molecular gas associated with star formation.

In the final stage, the review compared evidence from nearby galaxies with observations of quasars in the early universe. Nearby systems offer a closer view of how jets and winds interact with gas, while distant quasars show how early some black holes had already attained large masses. The synthesis linked each observation to the question it could address. It also distinguished quantities inferred from observations, such as black hole mass, from mechanisms explored in simulations, such as the redistribution of gas by jets. The analysis then grouped findings according to their relevance to seed formation, mass growth, or changes in star formation.

Results

Observations of distant quasars show that some black holes reached supermassive sizes early in cosmic history. One example is the quasar J1342+0928, whose central black hole was estimated to have a mass about 800 million times that of the Sun. The light observed from this quasar was emitted when the universe was approximately 690 million years old. Its age and estimated mass place a time constraint on models of black hole formation. A seed left by the collapse of a massive star would have had to gain more mass over the same interval than a heavier seed formed through the direct collapse of gas. Starting with a heavier seed or undergoing periods of particularly rapid accretion can help account for the observed mass. arxiv.org

The literature identifies gas accretion and mergers as two processes that can contribute to black hole growth. During accretion, gas moving toward the black hole forms a rotating flow and releases energy. This energy can make the center of the galaxy visible as a quasar during a period of intense activity. Mergers provide a different route to mass growth. When two galaxies combine, their central black holes can eventually form a pair and merge. Over a galaxy's history, the relative contribution of these processes depends on the availability of gas and on how often the galaxy encounters other galaxies containing black holes. science.nasa.gov

Observations of the radio galaxy 4C+29.30 illustrate how energy from the region around a black hole can reach surrounding gas. Radio images show two jets extending from the galaxy's center, while X-ray images reveal hot gas in regions affected by those jets. The two types of observations describe different parts of the same interaction. The radio data trace the jets, and the X-ray data reveal the hot material with which they interact. The jets can therefore transfer

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energy beyond the immediate vicinity of the black hole. When gas is heated, it must cool before it can contribute to the formation of new stars. NASA Science

Evidence of energy transfer also appears in galaxy clusters. In the cluster MS 0735, X-ray observations reveal large cavities in the hot gas surrounding the central galaxy. These cavities are associated with an outburst that launched jets from the region around the galaxy's central black hole. Their presence shows that jets can displace gas across regions extending beyond the galaxy itself. This process can affect the supply of gas that cools and flows toward the galaxy, where it could fuel further black hole growth or become available for star formation. chandra.harvard.edu

Across the systems examined, gas plays a role in both black hole growth and the response of the galaxy. Gas moving inward can increase the mass of the central black hole and power an active galactic nucleus. Energy released during this activity can then heat or redistribute surrounding gas, changing where it is available and how readily it can cool. Early quasar observations constrain the time available for growth, while observations of jets and X-ray cavities show how black hole activity changes the environment in which later growth and star formation take place. arxiv.org

Discussion

The discovery of a black hole with an estimated mass of 800 million Suns in a universe only 690 million years old makes the timing of growth central to the study of supermassive black holes. A heavier seed begins closer to the observed mass, so it requires fewer rounds of growth at the same proportional rate. A lighter seed can also reach a large mass if gas reaches it early and continues to arrive during sustained or repeated episodes of rapid accretion. The quasar therefore narrows the range of plausible growth histories. Its mass is best interpreted alongside the starting mass of the seed, the rate of accretion, and the length of time during which gas was available.

The supply of gas helps explain why the evolution of a black hole depends on conditions in its host galaxy. Gas can accumulate in a galaxy while only a fraction reaches its center. To move inward, orbiting gas must lose some of its angular momentum, the property that keeps it in orbit. Gravitational interactions during a galaxy merger can help redistribute angular momentum and direct gas toward the center. The same merger can bring two central black holes into the combined galaxy, where they may eventually merge. A single galactic encounter can therefore contribute to black hole growth through two processes that operate on different timescales.

The observations of 4C+29.30 and MS 0735 illustrate how energy released during accretion can travel well beyond the central black hole. Jets can deliver energy to hot gas around a galaxy or within a galaxy cluster. When this gas stays hot longer, less of it can cool and flow inward over the same period. This can reduce the supply of cold gas from which new stars form. The effect may outlast an individual episode of jet activity because heated gas takes time to cool. In dense regions, pressure from a jet or an outflow can also compress gas. The response then depends on whether that gas can cool and remain concentrated long enough for gravity to draw it together.

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These interactions help explain why black hole activity and star formation can vary over a galaxy's lifetime. An influx of gas can fuel both processes. As the black hole grows more active, the energy released near it can redistribute the gas that supplies them. A later influx can renew activity in the nucleus and provide material for further star formation. The relative timing matters when interpreting observations. A bright nucleus records an active phase of accretion, whereas the galaxy's population of stars reflects conditions over a much longer period.

Observations at different wavelengths help relate these timescales to the physical state of the gas. Radio images show where jets carry energy, X-ray images reveal how hot gas responds, and millimeter observations trace cold molecular gas that can supply star formation. Comparing these measurements within a galaxy can show where the material needed for new stars lies relative to the regions affected by nuclear activity. Distant quasars extend this comparison back to the early stages of galaxy formation.

Conclusion

Supermassive black holes can develop from smaller black holes formed early in the history of the universe. The collapse of massive stars and the direct collapse of large gas clouds offer two possible routes to the formation of these initial black holes. Gas accretion and mergers can increase their masses over time. The presence of extremely massive black holes in early quasars places an important constraint on these processes. Models must account for how much mass a seed had at formation and how quickly it could grow within the available time.

The growth of a central black hole is closely linked to the movement of gas in its host galaxy. Gas flowing toward the center can feed the black hole, while energy released during accretion can heat or displace gas elsewhere in the galaxy and beyond it. These changes can alter the supply of cold gas needed to form new stars. The effect depends on where the energy is deposited and how the gas responds to heating, compression, or displacement.

Observations of distant quasars provide evidence about the timing of early black hole growth. Radio and X-ray observations of nearby systems show how jets transfer energy to surrounding gas. Together, these observations connect the growth of supermassive black holes with changes in the gas that supports star formation and shapes the evolution of galaxies.

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