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# A New Population of Active Galactic Nuclei

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## Taken from: Hubble 2006 Science Year in Review

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# A New Population of Active Galactic Nuclei

*Amy J. Barger*

Astronomers are pathfinders who explore the universe as Lewis and Clark explored the West—to discover what is there, learn how it relates, and reveal the forces at work. Just as the pioneers charted the land and engaged the people to construct a narrative about the new frontier, astronomers map the breadth and depth of the cosmos, counting and characterizing the objects to determine the main elements and basic processes for the true story of the sky. In recent years, "active galactic nuclei," or AGN, have become a central theme in the cosmic story. From several lines of research, astronomers have learned that AGN are major agents of change in galaxies, which are the building blocks of the universe. Three other articles in this book discuss topics related to AGN and their roles in galaxy evolution: jets (Perlman) and outflows (Arav), and "red-and-dead" galaxies (Davis & Faber). This article discusses a newly discovered population of AGN in relatively nearby galaxies.

AGN are luminous objects at the centers of galaxies. They emit staggering amounts of energy across the whole spectrum of light—at radio, infrared, visible, ultraviolet, and x-ray wavelengths. The most luminous AGN are "quasi-stellar objects," or QSOs, which far outshine all the hundreds of billions of stars in their host galaxies.

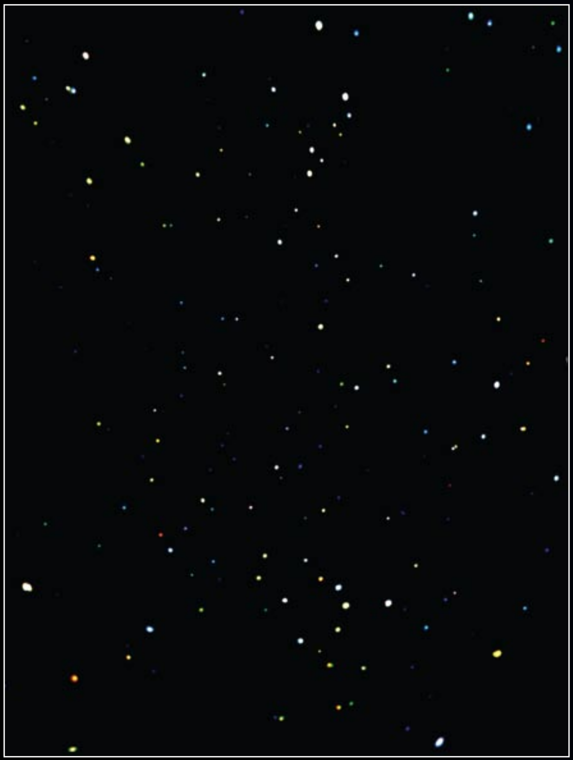
The only source of energy capable of fueling AGN is the gravitational energy released by material falling towards a small, unseen object with a mass that is millions to billions of times the mass of the Sun. AGN are observed to fluctuate in brightness on timescales of days, or even hours. From this timescale and the speed of light, astronomers can infer that the object is indeed very small, being comparable in size to the planetary orbits around the Sun. The luminous material itself—ionized gas—moves at very high velocities, from which astronomers infer that the gas revolves around an extremely heavy, but unseen object: a supermassive black hole.

NASA and the European Space Agency (ESA) jointly released this image of the magnificent galaxy Messier 82 (M82). M82 is a prototypical active galaxy, with strong multiwavelength emissions from its center. This mosaic image combines the light of x-rays from the *Chandra Space Observatory,* infrared light from *Spitzer,* and optical wavelengths from *Hubble*. The galaxy is remarkable for its bright blue disk, webs of shredded clouds, and fiery-looking plumes of glowing hydrogen blasting out of its central regions.

Black holes are so dense that nothing, not even light, can escape their gravitational pull. Stellar-mass black holes are known to form from the collapse of massive stars at the end of their lives, but how *supermassive* black holes form—with their masses of several million to several billion times the mass of the Sun—is still an enigma. *Hubble* observations of the orbital motion of stars and gas around the nuclei of local galaxies reveal that supermassive black holes reside at the centers of nearly all galaxies, including our own Milky Way. The supermassive black holes at the centers of local galaxies, which must have been created during an earlier phase of active accretion, are now dormant, having run out of fuel to consume. By taking a census of accreting supermassive black holes in the universe's past, astronomers hope to piece together how local supermassive black holes came to be.

The luminous portion of the AGN is an accretion disk around the black hole, which captures material from afar. The material in the disk loses energy, probably via interaction with magnetic fields. The material spirals into the event horizon of the black hole—the surface from which neither light nor matter can emerge—and disappears. The gravitational energy released in this journey heats the accretion disk, producing the light of the AGN and driving the jets and outflows. In turn, the jets and outflows are feedback mechanisms that govern the AGN: they blast interstellar gas out of the galaxy, ultimately starving the accretion disk of new material and shutting down the AGN.

Distant supermassive black holes can only be identified while they are accreting. The first phase of the census involved obtaining optical spectra of those distant sources whose appearances in optical images suggest that they may contain AGN. Spectroscopy is a powerful technique that splits light into colors, just as a prism splits sunlight into the colors of a rainbow. A spectrum is a record of the amount of light measured at every color, or wavelength, which can show emission or absorption features that astronomers can use to identify sources as AGN and to measure their distances. The general expansion of the universe stretches the light waves emitted from distant sources during their journey to us. This stretching causes the light waves to become longer, and hence, to appear redder. This stretching is referred to as the "cosmological redshift," and once we assume a cosmological model, it tells us the distance to an object and its age. (See the sidebar on QSO spectra in Arav's article on AGN outflow.)

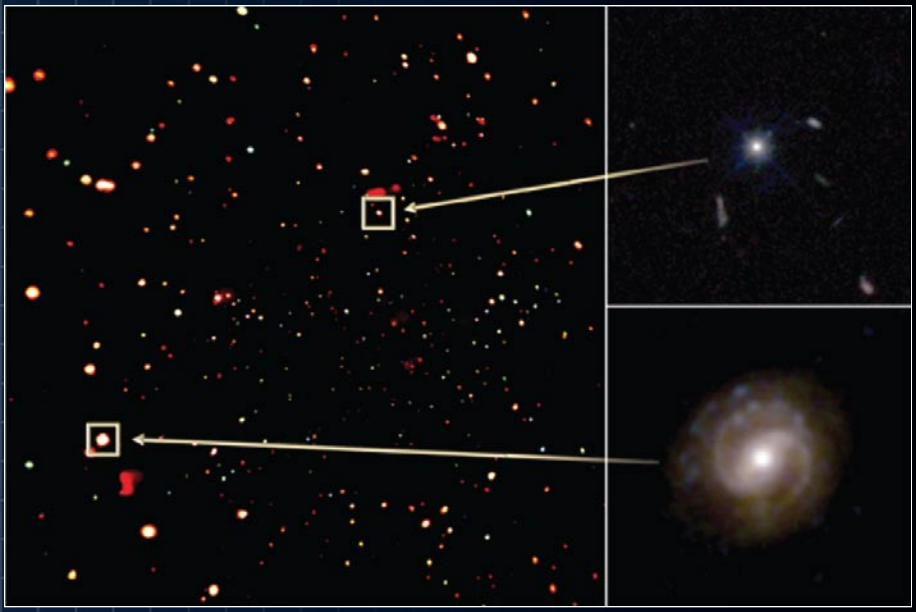


*Chandra* x-ray and ground-based optical images of the Hubble Deep Field–North region. The Hubble Deep Field–North was originally a 10-day exposure by *Hubble* of a tiny region of sky located in the Big Dipper. The field has since been intensively observed at a number of different wavelengths using many different telescopes. These new images cover a much wider area than the original *Hubble* images. The left image is a composite of three x-ray energy ranges. Most of the sources in the x-ray image are active galactic nuclei powered by accretion onto supermassive black holes. The right image is a composite of three different optical images observed with the 8.2-m Subaru telescope on Mauna Kea in Hawaii. There are many more sources visible in the optical image, because star-forming galaxies are far more common in the universe than active galactic nuclei.

The first phase of the AGN census, at optical wavelengths, found that the universe went through a "QSO era" a few billion years after the Big Bang, when QSOs (the most luminous AGN) were much more common than they are today. After that era, the number densities of such extremely luminous, accreting, supermassive black holes dropped off dramatically. Thus, from the optical data gathered, it seemed that most of the action took place at early times, after which the universe settled into a sedate middle age.

But wait! Optical observations cannot detect AGN that are hidden by gas and dust; therefore, the optical census provided only a partial glimpse of the demographics of these sources and their roles in galaxy evolution. Fortunately, there are ways to detect *hidden* black holes, the best of which is by observing the high-energy x-rays that originate at the closest detectable distances to the supermassive black holes, within a few multiples of the radius of the event horizon.

X-ray astronomy can only be performed from space, because Earth's atmosphere blocks x-rays from reaching its surface. In 1962, an x-ray telescope built by a team led by Riccardo Giacconi revealed a uniform x-ray glow coming from the sky. (Giacconi, who won the Nobel Prize in Physics in 2002, was the first director of the Space Telescope Science Institute.) Subsequent satellite observatories confirmed and extended the measurements of this glow to higher energies, but the individual galaxies that we now know produce it remained unknown for decades. A major reason for this was the same effect that reduced the count of optically identified AGN: the cocooning of many supermassive black holes by gas and dust. Light emitted in the AGN accretion process at wavelengths between infrared and low-energy x-rays are absorbed by the surrounding gas and dust, making the sources too difficult to identify at those wavelengths.



*Chandra* x-ray image with two optical counterparts from *Hubble* imaging. The image to the left again shows the deep *Chandra* image of the Hubble Deep Field–North region. The optical counterparts to two of the x-ray sources identified in the *Hubble* Advanced Camera for Surveys images of this field are shown in the images to the right. The top right image shows a blue, quasi-stellar object, where the emission from the accretion onto the supermassive black hole at the host galaxy's center outshines the host galaxy's light. The bottom right image shows a beautiful spiral galaxy with an active nucleus obscured by dust and gas. If it were unobscured, the nucleus would probably be at least 10 times brighter, swamping the light from the rest of the galaxy. This source would not have been identified as an active galactic nucleus without the x-ray imaging data.

The *Chandra X-ray Observatory*, launched by NASA in 1999, revolutionized studies of supermassive black holes. Not only does *Chandra*'s great sensitivity detect high-energy x-rays, it also accurately pinpoints their locations, which enables astronomers to follow up with other telescopes to learn more about the nature of the x-ray sources. For example, even if a central black hole is obscured at optical wavelengths, once the x-ray observations show which galaxy contains it, optical spectroscopy can be used to determine the distance to that host galaxy. Then, *Hubble*'s high-resolution imaging can be used to determine whether the host galaxy is currently undergoing—or has recently undergone—a merging event with another galaxy, which could provide new fuel for the galaxy's AGN.

The deepest x-ray survey to date is the 2-million-second-long *Chandra* observation of the region of the Hubble Deep Field–North. In a side-by-side comparison of the *Hubble* optical image with the *Chandra* x-ray image, one sees that there are many more sources in the *Hubble* image. This is because most galaxies are dominated by star formation, and emission from star formation peaks at optical wavelengths. Therefore, *Hubble* can easily detect star-forming galaxies. In contrast, the x-ray emission from star formation is weak, because it is a much less energetic process than black-hole accretion, and even this deepest of *Chandra* images only begins to detect star-forming galaxies. Thus, the x-ray image is dominated by luminous, accreting, supermassive black holes, and there are far fewer of these than there are star-forming galaxies.

When astronomers looked at the optical counterparts to the *Chandra* x-ray sources, they found great diversity, ranging from optically identifiable QSOs, to bright host galaxies with no emission-line AGN signature in their optical spectra, to extremely faint sources for which it was difficult to obtain a redshift from optical spectroscopy. For these latter sources, astronomers used *Hubble* optical and ground-based near-infrared images at various wavelengths to infer the redshifts.

In fact, astronomers were able to re-find all of the optically identified QSOs in the Hubble Deep Field–North using the x-ray data, which provided a good check on the techniques. The truly exciting discovery was that the known QSOs were not the only accreting supermassive black holes in the field. Astronomers discovered a new population of AGN that were not discovered by optical observations alone, and, much to their surprise, these newly discovered AGN did not just form in the QSO era!

In fact, these AGN reside in relatively nearby galaxies. Although their behavior is *not* the same as the distant QSOs—QSOs are voracious consumers, while these new sources are much more moderate—there are so many that together they account for a substantial fraction of the total energy released by AGN over the history of the universe.

Black-hole accretion was not just a phenomenon of the distant past; the middle-aged universe was just good at hiding the fact that it was still an active and exciting place!

Thanks to the complementary powers of the Great Observatories, we are completing the census and demography of AGN, which are the leading agents of galactic evolution. Two hundred years after Lewis and Clark, their spirit is alive and their methods are at work on the cosmic frontier.

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The rich field of galaxies seen here in a section of the image known as the Hubble Deep Field–North has also been targeted by the other NASA great observatories, *Chandra* and *Spitzer*. Such coordinated observations enable scientists to study the relative amounts of electromagnetic radiation emitted by these distant sources and identify active galactic nuclei.