

Long X-Ray Observation Probes Black Hole Infall

What do you get if you look at an active galaxy for five days? The answer, in the form of this lopsided iron emission line, is compelling evidence of matter whirling closely and relativistically around a supermassive black hole. And, if you're willing to bet on a 3-sigma result, the small dip just below 6 keV provides the first tentative evidence of matter actually falling into a black hole.

For the past 20 years or so, astronomers have assumed that the luminous, variable cores of certain galaxies—known as active galactic nuclei (AGNs)—are powered by the accretion of matter into a supermassive black hole. Also part of the AGN paradigm is a rotating disk-shaped reservoir of matter whose gravitational energy ultimately fuels the AGN. (See Roger Blandford and Neil Gehrels's article, "Revisiting the Black Hole," *PHYSICS TODAY*, June 1999, page 40.)

Evidence for the presence of disks in AGNs comes partly from iron emission lines, whose energy (6.4 keV) and relatively high luminosity are consistent with material fluorescing in a large region, assumed to be a disk, around the hole and illuminated by the central x-ray source. But evidence for disk-hole interaction had been circumstantial until the Advanced Satellite for Cosmology and Astrophysics (ASCA), a Japanese-US x-ray astronomy satellite, observed a distorted iron emission line in the AGN known as MCG-6-30-15.¹ These distortions were consistent with the combination of two effects that arise from the black hole's intense gravitational field—gravitational redshift and the relativistic Doppler shift.

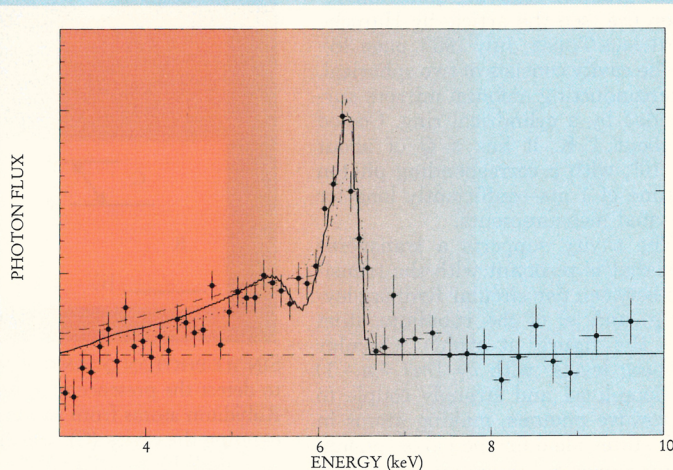
Now, by looking with ASCA at a brighter target (NGC 3516) for longer, Paul Nandra and his colleagues have probed an AGN's inner disk in unprecedented detail.² They've found, for example, that the shape of NGC 3516's emission line can be plausibly modeled in terms of a rotating black hole. (A nonrotating black hole is also consistent with the data, but some of the parameters of the corresponding model are contrary to astrophysical expectations.)

Thanks to the length of the observation, Nandra's team, which is based at NASA's Goddard Space Flight Center in Greenbelt, Maryland, has also been able to study how the continuum, the line core, and the redshifted and blueshifted wings of the line vary in time. The continuum and core seem to be correlated with each other, as do the blue and red wing. Curiously for a line supposed to originate in reprocessed emission, the line wings vary more than the continuum—evidence, suggests Nandra, that another process plays a part.

One of the most intriguing—and tantalizing—aspects of the NGC 3516 observation is the 3-sigma detection of an absorption

feature at 5.89 keV (that's the small depression to the left of the main peak). It could arise from matter being caught in the act of falling into the black hole.

As it approaches the hole, a blob or sheet of matter could find itself between ASCA and the x-ray source, absorbing some



of the x rays that would otherwise reach ASCA's detectors. Resonant absorption would result in a redshifted, broadened absorption line—redshifted because of the gravitational redshift, and broadened because of tidal effects.

Although the data are consistent with this interpretation, other explanations are conceivable. For instance, gravitational redshift could be responsible without the need to invoke infall. But, more important, the absorption line itself is of only marginal statistical significance and, given the modest resolution of ASCA's detectors, possibly unresolved.

With hopes of discovering more about black holes and their environments, Nandra and other AGN watchers avidly anticipate the launches in 2000 of the European Space Agency's XMM mission, which will collect substantially more photons than ASCA, and of the Japanese-US Astro-E, which will provide significantly better energy resolution.

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References

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the ENS experiment shows potential for quantum information processing. One way to get either zero photons in the cavity or one is to send in an atom in the excited state, but let it interact for a shorter time so that it has only a 50% chance of emitting a photon. If a second atom traverses the cavity for a QND measurement, it becomes entangled with the first atom. Just recently, Haroche tells us, his group has extended this method to entangle a third atom, as well, using a sequence of coherent emission, QND reading, and absorption of zero photons or one.

Because of their necessarily low

atom fluxes and limited detector efficiency, however, the ENS researchers had to collect data for 16 hours. One possible alternative in the optical domain has been demonstrated by Jeff Kimble's group (Caltech): They have succeeded in trapping a single atom inside an optical QED cavity in a regime of strong coupling.⁵

With these advances in optical and microwave cavity QED, as well as in ion traps, researchers are learning to make the building blocks for quantum information processing, according to Peter Zoller (University of Innsbruck). "I'm optimistic that in a few years we'll

have different systems, in the context of cavity QED as well as ion traps, for implementing quantum logic on the level of five to ten qubits."

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References

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