Research News

Gamma Rays from Cygnus X-1

Eight-year-old satellite data has provided new insight into how matter accretes into a black hole; the same mechanism could be at work in quasars and other active galaxies

An analysis of 8-year-old data on Cygnus X-1, the galaxy's best-known candidate for a black hole, has revealed episodic emissions of million-electron-volt (MeV) gamma rays. The effect is so strong that for a period of 2 weeks in 1979, gamma rays accounted for half of Cygnus X-1's total emitted energy.

This discovery seems to verify a decade-old theoretical model in which the material falling into the black hole grows hot enough to generate a "pair cloud"—a bubble of matter saturated with electron-positron pairs. This model, in turn, could improve astronomers' understanding of the much larger black hole thought to occupy the center of our own galaxy, as well as the still larger black holes thought to power quasars and other active galaxies.

"Cygnus X-1 is just a fascinating object," says James Ling of the Jet Propulsion Laboratory (JPL), who presented the results at a recent gamma ray workshop in Washington, D.C.* "Just when we get a better understanding of the system, it hits us with more stuff to chew on."

As its name suggests, Cygnus X-1 was the first x-ray source to be discovered in the constellation of Cygnus, the Swan. In the early 1970's moreover, it was recognized as the first object whose mass and other parameters were consistent with its being a black hole. According to the best current models, Cygnus X-1 is actually a binary system located about 7500 light-years from Earth. One component is a supergiant star of about 30 solar masses. The other is the black hole itself, an object having about ten times the mass of the sun and a radius of about 30 kilometers. (More precisely, this is the Schwarzschild radius, or "event horizon"; anything that falls inside this radius will inevitably keep falling until it is crushed by the space-time singularity at the center of the black hole.)

What makes this system into an x-ray source is an act of celestial cannibalism. As the two companions orbit each other, the black hole siphons off matter from the supergiant and swirls it into a flat, circular whirlpool known as an accretion disk. Here, where gas and dust are slowly spiraling inward toward the event horizon, the viscosity and pressure are enough to generate temperatures in the billion-degree range. And those temperatures, in turn, are so high that the disk shines primarily by x-rays instead of by ordinary light.

Cygnus X-1's gamma-ray excursions were first noticed in 1985, as Ling and his colleagues were systematically going through gamma-ray data taken during 1979 and 1980 by the High Energy Astronomical Observatory-3 (HEAO-3) satellite. Included were 170 days of observations of Cygnus X-1, says Ling. The gamma-ray flare itself was confined to a particular 2-week interval in 1979—as it happens, the same 2-week interval that also saw a decrease in the object's hard x-ray emission. Indeed, the energy balanced quite closely: within experimental error, the gamma rays were being produced at the expense of the x-rays.

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Ling and his colleagues spent the next year and a half convincing themselves that their data were, in fact, real. "The analysis is not simple," he says, particularly since Cygnus X-1's x-ray signal is itself highly variable. "We've been struggling with the data, putting the results through all possible tests."

In the end, however, the researchers convinced not only themselves but two associates at the Lawrence Livermore National Laboratory, Edison P. Liang and Charles P. Dermer. In 1979 Liang had proposed a model of the accretion process that predicted exactly this kind of gamma-ray emission. Depending on the viscosity in the disk, he had argued, temperatures in the inner part of the accretion disk near the black hole horizon could actually soar as high 5 billion K. Not only would this be hot enough for the disk to shine with gamma rays, but it would be hot enough for the gamma rays to be in thermal equilibrium with electron-positron pairs. (That is, every pair that annihilated to form two gamma rays would be balanced by two other gamma rays that interacted to produce a new pair.) Moreover, the pairs would far outnumber the ordinary particles.

"As soon as we were convinced the data from JPL were real," says Liang, "we started doing first-principle numerical modeling based on the spectrum alone, and used the Livermore supercomputers to determine the physical conditions and geometry of the gamma-ray source."

Liang and Dermer's results suggested that during the 1979 excursion, the inner regions of the accretion disk swelled into a superheated sphere about 250 kilometers in radius, or about eight times the Schwarzschild radius. Since this was the region occupied by electron-positron pairs, they dubbed it the "pair cloud."

Although the researchers cannot yet explain why this pair cloud seemed to swell and then contract again, their model does produce a good fit of the gamma rays' spectrum and intensity. It also explains the curious see-saw in the energy balance: as the bubble swelled to produce gamma rays, there was less room on the disk to produce x-rays.

Thus, it seems that the Cygnus X-1 gamma rays have provided astronomers with new insight into how material falls into black holes. It has also given them a new tool to learn more. "Now that we know that the gammas came from very close to the event horizon," says Liang, "we can start to do very careful diagnostics of the region."

In addition, he says, the same mechanisms may scale up to the million-solar mass black hole at the center of the Milky Way galaxy, and to the billion-solar mass black holes that presumably power the quasars. ■

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* Workshop on Nuclear Spectroscopy of Astrophysical Sources, Washington, D. C., 13–16 December 1987.

ADDITIONAL READING

J. Ling, W. A. Mahoney, W. Wheaton, A. S. Jacobson, "Long-term gamma ray spectral variability of Cygnus X-1," *Astrophys. J. Lett.* **321**, L117 (1987).

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