Where Space Is Sharply Curved

If Cygnus X-1 really is a black hole, it is a natural astrophysical working place to study general relativity

"The discovery of a black hole would be for general relativity what the discovery of the photon was for quantum theory and the physics of the microcosm."

by Dietrick E. Thomsen

As soon as the theory of general relativity was propounded, astronomers and physicists made ready to test its observational predictions. There was of course the excess motion of the perihelion of the orbit of Mercury, which the theory had been designed in part to explain. There was the gravitational bending of light beams (verified at the eclipse of 1919), the gravitational redshifting of light and the gravitational retarding of light (both verified in recent years).

Light rays and the planet Mercury would exist without the theory of general relativity. Its effects on their behavior are small. But there is a class of objects whose existence is predicted by general relativity and which do not exist if the theory in some form is not true. These are the black holes, objects that have collapsed under the influence of their own gravitation until they are so dense and have such strong gravitational fields that neither matter nor radiation can escape from their surfaces.

To a general relativist a black hole is an example of extremely curved space. In and around it the effects of general relativity are not minor; they are dominant, and they determine the nature of the phenomena that occur. The discovery of an actual black hole would provide an astrophysical working place for general relativity, a region where the effects of space curvature could be studied readily rather than having to be sorted out as tiny corrections to the nearly flat space that surrounds ordinary objects. As Remo J. Ruffini of Princeton University puts it, the discovery of a black hole would be for general relativity what the discovery of the photon (also, by the way, associated with Einstein) was for quantum theory and the physics of the microcosm.

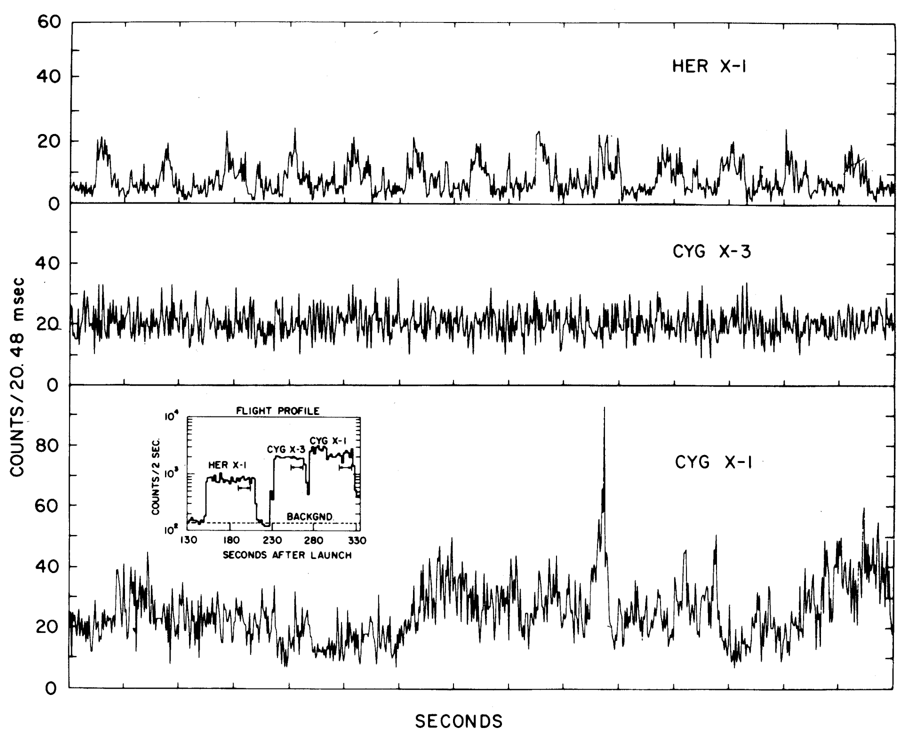
Ruffini believes, and has believed for more than a year, that at least one black hole is currently under observation (SN: 1/13/73, p. 28). Controversy rages, and to the discussion Ruffini now brings theoretical arguments and observational evidence, some of which was barely analyzed in time for him to use it at the meeting of the American Physical Society two weeks ago in Chicago.

Ruffini's candidate for a black hole is Cygnus X-1, one of a newly discovered class of celestial X-ray sources, X-ray binaries. Up to a point there is general agreement as to what these binary sources are: They are systems in which a more or less normal star is gravitationally bound to a highly condensed dark companion. The usual explanation as to how the companion got condensed is that it is the last stage of stellar evolution, what is left over after a supernova explosion.

Matter streams out from the normal star and falls onto the dark companion. The streaming matter forms a rotating disk around the dark companion in which pieces of matter gradually spiral inward until they fall on the dark companion. As they do so they convert energy they gain through their fall to X-rays. (The matter in the disks is electrically charged ionized plasma, not neutral gas, so it has means to do this.)

The argument starts over the nature of the condensed body. The main candidates are black holes and neutron stars—though a few observers may hold out for white dwarfs. To make the case for black holes or for a black hole one needs a way of distinguishing observationally between the two. Ruffini provides a way.

It has to do with magnetic fields. Stars have magnetic fields. When they collapse, even through the violence of a supernova explosion, they should retain those fields. Thus neutron stars and black holes can have magnetic fields. But in the configuration of those fields lies the difference. A neutron star



Princeton Univ.

Spike in emission of Cyg X-1: A 5-millisecond orbit around a black hole?

biomedical sciences

Immune protection and exercise

The body is protected against foreign compounds by two major kinds of cells—B and T lymphocytes. Since these cells provide different kinds of immune protection—humoral and cell-mediated immunity—scientists would like a better idea of their role in various diseases. For instance, B cells have been found to increase markedly and T cells to decrease markedly in leprosy patients compared with healthy persons. This suggests that T-cell deficiency, not B-cell deficiency, may be crucial in the course of this disease.

Before immunologists can better understand B and T cell roles in diseases, though, they need more understanding of the roles they play in healthy persons under various physiological conditions. Vigorous exercise seems to rapidly mobilize B cells, but not T cells, C. M. Steel, Judith Evans and Marilyn A. Smith of the Western General Hospital in Edinburgh report in the Feb. 8 NATURE: The cytogeneticists also found an unpredictable fluctuation in the B-to-T-cell ratio in the blood of healthy persons in the course of their normal daily activities. The cause remains to be determined.

Sickle-cell test for newborns

Although the ideal treatment for sickle-cell anemia has not yet been found (SN: 2/16/74, p. 104), physicians can still abate the pain of sickling crises and extend patients' lives, provided they detect the disease early enough.

One out of 600 babies born to black Americans has sickle-cell disease, yet there has been no means of screening these newborns for it. Now such a test has been devised by Howard A. Pearson and his colleagues at the Yale University School of Medicine. The test consists of submitting blood from the umbilical cord to a technique called electrophoresis, which reveals abnormal hemoglobin molecules.

"Our experience has shown that routine screening of cord blood specimens from black infants . . . is practical and could be provided at a cost of $3.50 to the patients," the pediatricians report in the Jan. 28 JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION. "The test is rapid, taking less than two hours to complete, requires simple, inexpensive equipment and can be performed by individuals with little technical training."

How interferon works

Ever since interferon was discovered as a bodily protein defense against viruses, there have been fervid attempts both to exploit interferon therapeutically (SN: 2/16/74, p. 102) and to understand how it protects cells.

A number of scientists have reported that interferon protects cells by helping them distinguish between viral messenger RNA and host-cell messenger RNA. Then the cells are able to translate their own genetic (DNA) messages and ignore those of the virus. But how do interferon-treated cells make the distinction? A tentative answer is given by Hilton B. Levy and Freddie L. Riley of the National Institute of Allergy and Infectious Diseases, in the latest PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES (December 1973, Part II).

They analyzed messenger RNA from interferon-treated cells and from control cells. They found that the RNA molecules being translated were slightly larger than those of control cells. This change in size, they believe, was induced by interferon. The difference in size might well allow interferon-treated cells to tell their own RNA from that of viruses, and thereby translate only their own.

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can have a field that is not aligned with its rotational axis, but a black hole must be axially symmetric, and therefore its magnetic field must lie along its rotation axis.

A body with a skewed magnetic field will cause the production of a regularly pulsed X-ray signal, says Ruffini, and he argues that if we see such a signal, we are looking at a neutron star. In the case of the black hole a signal with sharp irregular bursts would appear. These bursts would represent a blob of matter spiraling in toward the black hole, and each blob would produce a sequence of them getting narrower and narrower as its orbit got smaller and smaller until it finally dropped into the hole. (Of course this picture requires a view more or less broadside to the disk. Looking at the edge, one would see a chaotic signal because of absorptions and reemissions of X-rays passing through the matter of the disk.)

What Ruffini has got, and what he showed the meeting, is observational evidence that seems to confirm this hypothesis. It comes from observations made by a rocket flown by workers at the Goddard Space Flight Center. The rocket recorded X-rays from Cygnus X-1, Cygnus X-3 and Hercules X-1.

Hercules X-1 shows a rather regularly pulsating signal and would classify according to Ruffini as a neutron star. Cygnus X-3 shows a chaotic signal, which means we are looking either at the edge of a disk or at a diffuse cloud totally surrounding the collapsed object. The real goody is Cygnus X-1. This shows what Ruffini calls a bursting spectrum, and at one point there is an extremely intense narrow burst. When this is further analyzed it shows three peaks, 5 milliseconds apart. When Ruffini got this information, he sat down and did some calculations. It came out that 5 milliseconds is about the time it would take a blob of matter to go around the nearest stable orbit to a black hole with 10 times the mass of the sun. Dynamical arguments lead to a mass on this order for the condensed body in Cygnus X-1.

"So strong an agreement between theoretical prediction and observed fact" clinches the argument for Ruffini. He tells us we may now begin to study the experimental physics of black holes. "We want to smoke out as much as we can" from the details, he says.

It is a strange world. A black hole with 10 times the sun's mass would have a diameter of 14.7 kilometers. Its density would be 10^{16} grams per cubic centimeter.

In the presence of such an object time and space behave strangely. For a distant observer, says Ruffini, time appears to be frozen. An observer moving along with the blob of matter orbiting the black hole would see a decay of the orbit that took a few milliseconds, but for a distant observer time stops at the boundary of a black hole. "For the first time we are probing what space-time structure is," he says, and what we learn from these paradoxical peculiarities may help us to a theoretical synthesis of the structure of the universe, a union of general relativity and quantum theory.

At the moment we have a theory of the macrocosm, general relativity, which is highly deterministic: A given set of initial conditions leads to only one result. Quantum theory, which rules the microcosm, is in contrast indeterministic: A given set of conditions can lead to several results, and all the theory can tell is the probability that any one of them will occur in a given instance. Physicists do not like the opposition between the two theories and have been trying for a long time to reconcile them. Perhaps, says Ruffini, the strange things that happen in the throat of a black hole may point the way to the union. □