APPOINTMENTS

Peter T. Flawn, acting president, University of Texas, Austin, appointed president of the university. . . . **George H. Vineyard**, deputy director, Brookhaven National Laboratory, appointed director of the laboratory. . . . **L. J. A. DiDio**, chairman, anatomy department, Medical College of Ohio, also to dean of graduate studies at the college. . . . **Henry A. Harbury**, chairman, biological sciences department, University of California, Santa Barbara, to chairman, biochemistry department, Dartmouth Medical School. . . . **David M. Kipnis**, professor of medicine, Washington University School of Medicine, to head, medicine department at the university. . . . **Leon D. Harmon**, staff member, systems theory research department, Bell Laboratories, to chairman, biomedical engineering department, Case Western Reserve University. . . . **Bruce W. Arden**, chairman, computer and communications sciences department, University of Michigan, to chairman, electrical engineering department, Princeton University. . . . **Roland J. Pellegrin**, professor of sociology, University of Oregon, to chairman, sociology department, Pennsylvania State University. . . . **Robert H. Kokernot**, chairman, pathobiology and comparative medicine departments, University of Texas, to chairman, environmental health and veterinary and zoological medicine departments, Texas Tech University. . . . **Ugo Fano**, professor of physics, University of Chicago, to chairman, physics department at the university. . . . **Kenneth C. Rogers**, acting provost and dean of the faculty, Stevens Institute of Technology, to president of the institute. . . . **Edward M. Eyring**, professor of chemistry, University of Utah, to chairman, chemistry department at the university. . . . **Edward H. Smith**, director of cooperative extension, New York State College of Agriculture and Life Sciences, to chairman, entomology department, Cornell University. . . . **Henri S. Havdala**, former chief, anesthesiology division, Chicago Medical School/University of Health Sciences, to chairman, new anesthesiology department at the school/university. . . . **John F. Kelly**, vice president, Campbell Institute for Agricultural Research to chairman, vegetable crops department, University of Florida.

RECENT DEATHS

Armand J. Eardley, 71; former dean, College of Mines and Mineral Industries, University of Utah; 7 November.

Emma L. Fisk, 80; professor emeritus of botany, University of Wisconsin, Madison; 9 November.

Richard T. Frost, 45; former vice president, Reed College; 9 November.

George W. Heise, 84; retired associate director of research, National Carbon Co. Laboratories, Ohio; 28 September.

Frank S. Horvath, 80; former professor of medicine, Georgetown University; 9 November.

Arthur Lejwa, 77; former professor of basic science, Long Island University; 27 October.

Heinz H. Magendantz, 73; former associate professor of cardiology, Tufts University; 6 November.

Leroy K. Pinnell, 62; dean emeritus of education, Eastern New Mexico University; 25 October.

Clement J. Schneider, 44; vice president for academic affairs, Creighton University; 20 October.

RESEARCH NEWS

X-ray Astronomy (III): Searching for a Black Hole

Of all the objects conceivably traveling through empty space, nothing would be more difficult to detect than a solitary black hole. No light comes from it, and the odds against seeing a black hole pass between the earth and some distant star are impossibly great. No one ever expects to see an isolated black hole, but a black hole in the vicinity of a normal star might at least give some clue to its presence.

When it was discovered last year that unusual objects orbiting other stars were emitting x-rays, questions about how a black hole might be identified suddenly became urgent. In 1967 I. S. Shklovsky of the Shternberg Astronomical Institute in Moscow had suggested that a black hole might be detectable if it were drawing in matter from another, normal star. Ya. B. Zel'dovich and I. D. Novikov at the Lebedev Institute in Moscow had suggested that if gas were drawn into a neutron star or a black hole the gas would become hot enough to radiate x-rays. The ideas of Shklovsky and Zel'dovich were only qualitative and fragmented descriptions of what might happen near a black hole. It is now becoming clear, from theoretical studies, how a black hole could radiate x-rays if it pulled matter off a close companion star. The matter would probably form a disk rapidly rotating about the black hole, and the x-ray emissions from the disk would be neither steady nor pulsed, but would probably fluctuate rapidly. In only 1 year the ideas talked about in the early 1960's have been examined, refined, and extended to the point that a coherent picture of how a black hole might radiate x-rays is emerging.

The satellite UHURU has discovered many x-ray sources orbiting other stars, but the source most often suggested as being a black hole is Cygnus X-1. The x-rays from Cygnus X-1 fluctuate extremely rapidly and randomly, as might be expected for a black hole trapping matter. A series of related observations with optical and radio telescopes seems to indicate that the x-ray source is so massive that it is probably a black hole, according to current theories of collapsed stars (*Science,* 3 November 1972). Objections have been raised to the claim, but the case is fairly strong and its significance as a motivation for further experiments and further study of black holes has been enormous.

Questions about the mass of Cygnus X-1 may be answered by further experiments, but questions about the sort of x-ray emissions expected from black holes can only be answered by theoretical calculations. The properties of an isolated black hole are now fairly well understood (*Science,* 19 March

1971). But because no matter or radiation ever escapes from a black hole after it crosses a line of demarcation called the event horizon, models for the production of x-rays must describe a physical situation outside that horizon —which might correspond to the surface of a classical object.

If matter is slowly accumulated from a star onto any closely orbiting collapsed object, it appears that a disk will be formed outside the object. The precursor to the current studies of disk models was a description of a disk model for a white dwarf in a binary system derived in 1968 by K. Prendergast and Geoffrey Burbidge. Disk models also describe a process by which matter could be accreted onto neutron stars in binary systems (*Science*, 9 March 1973). However, most of the x-ray emissions from a neutron star would take place on the surface of the star itself, whereas the disk would be the only vehicle available for production of x-rays near a black hole. As a particle fell into a neutron star, most of its energy would be released within the last 20 or 30 km before the surface. But because a neutron star has an extremely strong magnetic field the field would destroy the inner region of the disk by pulling matter down the field lines. Then in the case of a neutron star the disk would be irrelevant to the production of x-rays. In the black hole, however, there are surely no magnetic fields, so the disk will extend almost to the event horizon.

Speaking of Science

Physics at a Turning Point?—Interview with Freeman Dyson

Freeman Dyson has studied physical problems ranging from the effectiveness of wartime bombing operations to the subtleties of quantum electrodynamics, and he thinks that some of the most interesting new problems are connected with the discoveries of x-ray emissions in objects in our galaxy—the realm of objects that was once the exclusive preserve of astronomers. When interviewed recently in his office at one side of the towering Gothic center of the Institute for Advanced Study in Princeton, New Jersey, Dyson talked about his views.

Dyson is a physicist's physicist, a man who has contributed immensely to the important theoretical problems in the last three decades, and who is known for the lucidness and logical completeness of his writing. Born in Crowthorne, England, in 1923, he was only 19 when he began work in operations research, analyzing the effect of the British strategic bombing operation. He never earned a doctorate, but rose very rapidly as a young man to become a full professor at Cornell University at age 28. He is credited by many as being one of the founders of the theory of quantum electrodynamics, and has also contributed to the theories of statistical mechanics and matter in the solid state.

Out of all the results announced in the last year, Dyson thinks that new discoveries in x-ray astronomy and low-temperature physics may be the most revolutionary. Several scientists have reported strange behavior of helium-3 which may indicate that it can become a superfluid like helium-4 at very low temperatures. According to Dyson, "something is clearly going on, and it is clearly beating the theorists," but he thinks that the discoveries of new x-ray sources may be even more noteworthy. When asked whether he thought that the impact of discoveries with the x-ray satellite UHURU would be as significant as the discovery of radio pulsars, Dyson replied that it was impossible to predict how dramatically scientists' view of the world would be changed. "It's just like asking Galileo, 1 year after he first turned his telescope on Jupiter, what would be the future of astronomy."

This work is by far the most exciting thing to come out of the space program, scientifically speaking. We have found a whole menagerie of x-ray objects, perhaps 10 or 12 different classes. (At least one sort is thought to be a neutron star.) The exciting thing about neutron stars is that they offer a laboratory for physics under more extreme conditions than anything we have available here on earth.

Dyson doesn't think that it is possible to say whether any one object found by x-ray techniques is a black hole, but he points out that if these objects are black holes, it will be a turning point in physics. Some observers have questioned whether we will ever know for certain if any object is a black hole, but Dyson is optimistic.

Yes, we should quickly get the necessary evidence if we keep observing them. In 10 years I expect we'll be pretty damn sure. The most important thing we need is just larger detectors. The detectors now register only about 100 counts per second. In order to tell a black hole from something else, you would like to see what happens within a few microseconds. So you need to be able to detect a million counts per second. This means detector areas of a few square meters. Such detectors are not bigger or more expensive than what we have flown in satellites before.

Just the possibility that a black hole has been discovered has had a great influence on the ways scientists direct their energies, however.

The gravity people (those who study objects collapsed by gravitational forces, such as a black hole) have been very excited, I would even say they have been morally stimulated by the results of the x-ray experiments. A few years ago there were hardly any theorists working in this field. Now many people are working, and they are making great strides. The description of neutron stars is to some extent just a question of nuclear physics. If you know the properties of matter at super-high densities, you can compute the properties of a neutron star. But with a black hole, no computer can do it for you. For the first time since Einstein, people are truly making progress in understanding what his equations say.

The subjects that Dyson chose as significant were the results of research with very sophisticated instruments. Several theories proposed in the last year have also been hailed by many observers as significant, but perhaps it's not surprising that Dyson wasn't awed by them. As he said, "I'm a very theoretical man, so I have great respect for experiments."—WILLIAM D. METZ

A black hole could form a disk by pulling gas out of a companion star or by trapping gas leaving the companion as a stellar wind. In either case, the gas would probably flow around the black hole and be spread outward by centrifugal forces. From the top the disk would look mottled because there would be many hot spots across the surface, emitting x-rays. No one is certain yet what specific process would cause hot spots, but many effects could produce flares analogous to solar flares. (The reconnection of broken magnetic field lines, synchrotron radiation, or plasma instabilities are all mentioned as possibilities). The disk would be rotating rapidly, and hot spots would gradually move inward as they orbit the black hole.

Many people have contributed ideas to the currently accepted picture of disk-type accretion onto black holes. Following the discovery of close binary stars emitting x-rays in 1972, James Pringle and Martin Rees, now at the Institute of Theoretical Astronomy at Cambridge, England, and N. I. Shakura and R. A. Sunyaev at the Institute of Applied Mathematics in Moscow independently developed detailed nonrelativistic models of x-ray emissions. Models based on the general theory of relativity, which is necessary to properly describe phenomena very near the black hole, were subsequently developed by I. D. Novikov, I. S. Polnarev, and R. A. Sunyaev at the Institute of Applied Mathematics and Kip S. Thorne at Caltech, Pasadena, California.

According to the relativistic models of the disk, the thickness would be about 2 km near the black hole, with considerable thickening at radii greater than 100 km. The outer radius of the disk would probably be 10^6 km, and the disk would extend inward until it reached the smallest radius of a stable orbit for a particle. Thorne and the associates of Zel'dovich have calculated the time-averaged behavior for the radiation of x-rays. From this, the spectrum of energies expected from a black hole accreting matter can be determined, and the results are in good agreement with the spectrum from Cygnus X-1. However, many other models would give a similar prediction. In order to get a more detailed picture of the disk, theories of the vertical structure (which determines the 2-km height) and of fluctuations in the disk must be constructed. Such theories are necessary to predict in detail what variations in x-ray emissions would be expected. These calculations are far more difficult than predictions of the time-averaged behavior, and have only been begun. Sunyaev has done much of the work to date on a theory of fluctuations.

One possible type of fluctuation is that the center of the disk near the black hole might repeatedly blow apart, and then be reconstituted as more gas flowed in from the outer portions, as suggested by Martin Rees. Such fluctuations are possible if, as predicted for black holes with certain masses and accretion rates, the innermost regions of the disk are transparent. Then any decrease in emission from the inner part will cause its temperature to rise. But that will cause the region to expand, making radiation less efficient. The temperature rises more and eventually the center blows up. The time required for this is presumably a fraction of a second, and would most likely produce x-ray fluctuations.

Test for a Black Hole

Could some phenomenon other than a black hole or a neutron star accreting gas explain very short fluctuations of x-ray emission? Soon after Cygnus X-1 was discovered, scientists argued that because Cygnus X-1 fluctuated drastically in 50 msec, the size of the object must be no more than 0.050 light-seconds, which is far smaller that the diameter of the sun. However, the time scale of the fluctuations more exactly defines the size of the region emitting x-rays, which may or may not be the size of the underlying star. John Bahcall at the Institute for Advanced Study, Princeton, New Jersey, thinks it is possible that two normal stars orbiting very near each other and linked by a magnetic field could produce x-ray fluctuations as short as those observed for Cygnus X-1. He thinks that breaking and reconnection of the magnetic field lines would occur as the two stars orbited each other, and that the released magnetic energy could heat the plasma around the stars, thus producing x-rays. Because the hot region in the stellar atmosphere could be much smaller than the star itself, very short pulsations might be produced. However, the ideas mentioned by Bahcall have not yet been developed in enough detail to be tested by x-ray observations.

The research group of Ya. B. Zel'dovich has searched for criteria for determining whether certain x-ray emissions really come from accretion onto a black hole. The crucial measurement, Zel'dovich and his colleagues propose, may be the duration of the shortest fluctuation. Because of the construction of the x-ray detector on the satellite UHURU, it cannot detect fluctuations much shorter than 50 msec, but a larger detector could (see box).

The idea of Zel'dovich and associates is that the fluctuations may be caused by the gravitational focusing due to the black hole. Alternate focusing and defocusing of the x-rays by the curvature of space around the black hole could be so pronounced that the hot spot would seem to disappear once each rotation. The effect of the red-shift of x-rays from the moving hot spot would be similar. So the duration of the fluctuations would just be the period of one rotation of the hot spot. But the periods of particles moving around a black hole are very well known: unlike motion around bodies with weak gravitational fields, motion around a black hole has a minimum period. If the period were shorter than the minimum, the object would move inside the event horizon and disappear down the black hole. If a black hole of 1 solar mass is not rotating, the minimum period is 0.5 msec. If it is rotating at the maximum possible rate, the minimum period is expected to be 0.07 msec. The observation of a minimum period of less than 0.07 msec would mean that Einstein's theory of general relativity would be in trouble. Observation of a period between 0.07 and 0.5 msec would indicate the rate at which the black hole was rotating, if the mass could be determined from the orbit of the companion star.

Of course, further study could convince theorists that something other than the shortest stable orbit would determine the shortest fluctuation. For instance, will the hot spots live more than one orbit near the inner edge? A simplified theory by Sunyaev seems to indicate that they will live for many revolutions.

No doubt other objections are possible and will be made before the debate about the characteristics of black holes is settled. This is really not surprising, for few phenomena imagined in nature have puzzled either the theoretical physicist or the layman as much as the black hole. The surprising thing is that in less than 2 years both experiments and theories have been perfected to the point that there is a specific proposal of a measurement that could disprove the assumption of a black hole.—WILLIAM D. METZ