search & discovery

Evidence accumulates for a black hole in Cygnus X-1

Within the past year many observers have become convinced that Cygnus X-1 contains a black hole. The most recent evidence, reported at the December meeting of the American Astronomical Society in Tucson, is from an x-ray detector aboard a rocket; a group at the Goddard Space Flight Center reported seeing millisecond variations in intensity, suggesting a compact object. Other recent evidence has come from observations with the 61-cm telescope at the Lick Observatory and from a group at University College London, who have an x-ray telescope aboard the Copernicus satellite. As the evidence has mounted, so has the excitement. However, there are many holdouts taking a wait-and-see attitude.

The x-ray source Cygnus X-1 had been detected in early surveys in 1963–67. Then at the beginning of 1971, using the Uhuru satellite, a group at American Science and Engineering discovered the existence of large-amplitude x-ray pulsations; they concluded that the source was a collapsed object. This finding prompted many subsequent observations in x-ray, optical and radio wavelengths.

The next major step came when Cygnus X-1 was identified with the ninth-magnitude, 5.6-day period spectroscopic binary HDE 226868. An accurate measurement of position had been obtained by Uhuru. This position was refined with greater accuracy in a rocket flight by Saul Rappaport (MIT) and his collaborators, who obtained an error box of about 30 arcsec. Right in the middle of the error box is a radio source, which was observed to turn on in the spring of 1971, going from below detectable limits to a reasonably strong radio source at the same time (within a week of each other) as the x-ray intensity reported by Uhuru decreased by a factor of four. Since then the average level of both the x-ray and radio signals has been relatively unchanged. The radio source had been discovered by Robert Hjellming and Campbell Wade of the National Radio Astronomy Observatory and by L. Braes and G. K. Miley of Westerbork Observatory in the Netherlands.

In addition to the radio source being identified with the x-ray source, Thomas Bolton (David Dunlap Obser-

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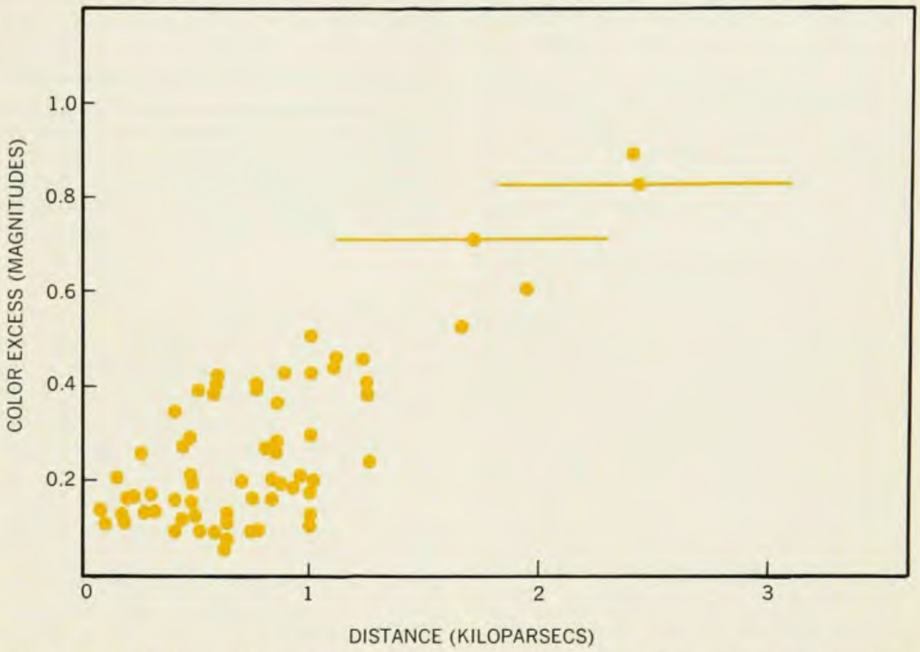

Color excess (reddening) as a function of distance for stars in the vicinity of HDE 226868. Horizontal lines correspond to uncertainties in the distance measurement. The color excess for HDE 226868 is 1.12, suggesting that its distance is at least 2.5 kiloparsec, that HDE 226868 is at least 30 $M_{\odot}$ and that the mass of its companion star is at least 6 $M_{\odot}$. Figure is adapted from J. Bregman, D. Butler, E. Kemper, A. Koski, R. P. Kraft, R. P. S. Stone, Ap. J. **185**, L 117 (1973), copyright 1973 by the American Astronomical Society.

Nuclear-magnetism studies at Saclay

A unique research effort at Saclay, headed by Anatole Abragam, is using the method of dynamic nuclear polarization to study nuclear ferromagnetism and antiferromagnetism and to observe so-called pseudomagnetism. The experiments on nuclear ferromagnetism and antiferromagnetism have yielded spin temperatures of a microdegree Kelvin or lower, achieving a record low temperature duly recorded in the "Guinness Book of World Records."

Furthermore, according to Harvard's Robert Pound, the Saclay group is the first to observe an ordered magnetic state due only to nuclear dipole–dipole interactions. The pseudomagnetism research now allows the systematic measurement of spin-dependent amplitudes for the scattering of neutrons by nuclei.

When we recently visited Abragam at the Centre d'Études Nucleaires de Saclay outside of Paris, he told us that he has been working in nuclear magnetism, the study of nuclear magnetic moments in bulk matter, since shortly after Felix Bloch and Edward Purcell did their pioneering work in nuclear magnetic resonance. Abragam, who is also professor of nuclear magnetism at the Collège de France, said that the research effort at Saclay on nuclear magnetism is not being done anywhere else in the world. "There is the danger that no one else is doing it because it's not interesting. On the other hand, some of the things we're doing I don't think anyone else could do." What is needed, he said, is access to a nuclear reactor, well-developed cryogenic, microwave and nmr techniques, and moderately sophisticated equipment.

The Saclay group uses the method of dynamic nuclear polarization, invented 15 years ago independently by Carson D. Jeffries (University of California, Berkeley) and by Abragam. With this technique it is possible to increase the gion. They are able to observe pseudomagnetic fields much smaller than in the preceding experiment, such as those associated with thermal equilibrium polarization in a magnetic field rather than with a dynamically polarized system.

Earlier experiments by others had measured the spin-dependent neutron scattering amplitude for hydrogen, deuterium, vanadium and cobalt. The Saclay workers have applied the pseudomagnetic precession technique to F^{19}, aluminum, Li^7 and sodium, and they plan to extend their technique to other materials.

Pound feels that the Saclay group now has a systematic tool for measuring spin-dependent neutron scattering amplitudes for all sorts of nuclei. —GBL

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vatory, Toronto) and independently, Louise Webster and P. Murdin (Royal Greenwich Observatory) studied the star HDE 226868, which was located at the radio position. They observed the optical spectrum of this ninth-magnitude star and found that the Doppler shift varied with a period of 5.6 days, suggesting that the star had some companion orbiting around it. Bolton found emission lines that were Doppler shifted in a way that indicated gas was flowing from the visible star to the companion.

New evidence for the identification of the optical and x-ray sources was recently announced by NASA, which reported that a University College London group, headed by Robert L. F. Boyd and Peter Sanford, using the Copernicus satellite, had correlated the variation in x radiation from Cygnus X-1 with the optical radiation and found evidence of the visible star's gas clouds swirling around and into a black hole. During three different 5.6-day periods the University College group observed the x-ray output from Cygnus X-1 in soft x rays at 6–20 Å (0.5–1.0 keV) and hard x rays, 1–3 Å (3–10 keV). In the soft x rays they observed a dip in intensity with a 5.6-day period. With the hard x rays they observed a similar but smaller dip in intensity near zero phase, where the x-ray source is on the other side of the optical companion. Earlier observations by Uhuru in hard x rays (2–20 keV) found no periodic intensity variations. Because higher energy x rays can penetrate more easily, there is less reason to expect to have much of an occultation effect in harder x rays.

Mass of x-ray source. If it is assumed that the ninth-magnitude star is a binary companion of the x-ray source, then using ordinary Newtonian dynamics of the binary system, one can infer something about the mass of the x-ray source, which is not observed optically. Assuming that the ninth-magnitude star is a B0 supergiant with a mass of about 30 $M_\odot$, one can determine the mass of the x-ray object to be greater than about 6 $M_\odot$.

(It is generally believed that a compact object must have a mass of at least 3 $M_\odot$ for us to be sure it is a black hole. There is a fairly well established upper limit for the mass of a nonrotating white dwarf—1.2 $M_\odot$ and for the mass of a neutron star—1.7 $M_\odot$; these limits can be increased somewhat if the objects are allowed to rotate very rapidly, but there are various arguments against being able to get as high as 6 $M_\odot$ in this way.)

The uncertainty in all these calculations, though, was whether the mass of the ninth-magnitude star was indeed 30 $M_\odot$, because there were other possibilities. For example, you could instead have a more highly evolved star of much smaller mass, which could mimic the optical appearance of a B0 supergiant with 30 $M_\odot$, provided it were much nearer. If that were the case, the mass of the x-ray source would also be much less.

Now with two companion reports from the Lick Observatory, published in the 1 November issue of *The Astrophysical Journal Letters* (by Bruce Margon, Stuart Bowyer and Remington P. S. Stone and by Jesse Bregman, Dennis Butler, Edward Kemper, Alan Koski, Robert P. Kraft and Stone), a better distance estimate of the binary system has established that the ninth-magnitude star is 30 $M_\odot$. These papers confirmed earlier distance estimates obtained by Bolton and by H. Smith, Margon and Peter Conti (Lick Observatory). In the new Lick work the observers looked at a large number of ordinary main-sequence stars in the same general direction in the sky and plotted the amount of reddening for these stars against distance, getting approximately a straight line. The reddening increases with distance because of interstellar dust along the line of sight. With Cygnus X-1 the amount of reddening is greater than any of the other stars; this implies that Cygnus X-1 is probably at least 2.5 kiloparsec away. This means that the ninth-magnitude star is at least 30 $M_\odot$, is indeed a B0 supergiant and that the mass of the x-ray source is at least 6 $M_\odot$.

Kraft pointed out to us some recent work by Jeremiah Ostriker (Princeton University) and Edward van den Heuvel (Astronomical Institute at Utrecht) that argues that if the B0 supergiant were burning helium in the core rather than hydrogen in a shell source, the mass could be as small as 10 $M_\odot$, in which case the mass of the unseen x-ray source would be 3.8 $M_\odot$.

The most recent evidence that Cygnus X-1 contains a black hole, reported at the Tucson meeting by Stephen Holt, Richard Rothschild, Elihu Boldt and Peter Serlemitsos of Goddard Space Flight Center, is that its x-ray output is flickering with variations as short as a millisecond, a behavior characteristic of a very small object. Previously the shortest variations observed in Cygnus X-1 were about 50 millisec; these were reported by the MIT group. A more recent analysis of the MIT data by Minoru Oda (University of Tokyo) and his collaborators, presented at the October meeting of the Astronomical Society of Japan, "indicate the existence of a number of flares with a duration of less than one millisecond." The Goddard team looked at Cygnus X-1 for about 1 minute with a large x-ray detector mounted on a rocket. They reported finding eight statistically significant bursts with duration about 1 millisec; during this time the intensity increases were as large as an order of magnitude. The bursts are superposed on slower variations, which had previously been reported by others.

Theory. Martin Rees (Plumian Professor of Astronomy at Cambridge University) told us that the x-ray behavior of Cygnus X-1 is just what you would expect from the most popular model. This says that gas is being captured from the companion star and forms a disc swirling around the black hole. Because of the viscosity of the disc, each element of the gas gradually loses angular momentum and spirals inward. Before the gas is gobbled up by the black hole, it gets very hot and emits x rays. Furthermore, the flickering on a rapid time scale can be explained, Rees said, because the orbital period of the gas just before it disappears is expected to be about a millisecond. On the other hand, a true periodicity, such as is seen from a neutron star, is not expected from a black hole because it has no hard surface, Rees notes; so he feels that it is gratifying that no periodicity has been observed in the flickering.

Despite the widespread conviction that a black hole has at last been found, some serious objections have been raised. For example, John Bahcall and Marshall Rosenbluth (Institute for Advanced Study) and Russell Kulsrud (Princeton University) have argued that accretion onto a compact object is not the only way to explain the x rays observed from binary systems. They propose an alternative model based on magnetic field twisting, in which the secondary x-ray source can be just a massive main-sequence star. The process is similar to that occurring in solar flares. The field lines linking the two stars become twisted when the two stars get out of phase, thereby producing x rays. No short-term periodicity is expected on this model either. —GBL

NAS-NRC defines goals for weather-modification work

Rapid progress in weather-modification techniques during the last seven years has prompted the National Academy of Sciences to issue *Weather & Climate Modification, Problems and Progress.* This report, prepared by the Panel on Weather and Climate Modification of the NRC Committee on Atmospheric Sciences, covers advances since 1966 (when a similar report was issued) and provides policy recommendations for the 1970's.

Three specific goals established by the panel are

- Identification by 1980 of the conditions under which precipitation can be increased, decreased and redistributed in various climatological areas through the addition of artificial ice and condensation nuclei.
- Development in the next decade of technology directed toward mitigating the effects of such weather hazards as hurricanes, hailstorms, fogs and lightning.
- Establishment of a coordinated national and international system for investigating the inadvertent effects of man-made pollutants, with a target date of 1980 for the determination of the extent, trend and magnitude of the effect of various crucial pollutants on local weather conditions and on the climate of the world.

An increasingly important issue, the report states, is the need to assess "what weather modification activities are in the public interest ... In considering the prospect of controlled weather modification, we are acutely aware that just because science and technology may develop the capability to modify weather there is no reason to assume that society should automatically use that capability."

At the administrative end the panel recommends that the National Oceanographic and Atmospheric Administration be assigned principal responsibility for a national program in weather modification. Further the NSF should continue to support research in all aspects of cloud physics and weather modification and "a national laboratory should be assigned primary responsibility for carrying out large weather-modification experiments involving theoretical, laboratory and field programs."

The price tag for implementation of the recommended program? Not less than $50 million. The panel recommends that "immediate action be taken so that the federal budget reflects increased requirements for cloud-physics research and weather-modification experimentation to the extent of at least a doubling of the current efforts."

Two papers propose laser-induced fission

Over the past two years interest has been mounting over the idea of using a laser to compress a pellet and cause thermonuclear fusion (PHYSICS TODAY, August 1972, page 17 and August 1973, page 46). Now two papers, one from the Lebedev Institute and one from the University of Nevada, propose using a laser to compress a pellet of uranium and cause fission. Such an arrangement could be used to make a miniature fission reactor, an intense neutron source, a particle accelerator or a very intense magnetic field, the authors say.

Both the paper from the University of Nevada, published in *Nature* by Friedwardt Winterberg[1] and the one from Lebedev, published in *JETP Letters* by G. A. Askar'yan, V. A. Namiot and Matvich S. Rabinovich,[2] propose using a laser to strike a uranium pellet surrounded by a hydrogen neutron reflector, and compress it, together with the neutron reflector, so reducing the critical mass by a very large value. Winterberg would use a 4.9-megajoule laser incident on a 3.2-mm-diameter pellet without a neutron reflector, and 2.3×10^5-joule laser for a 1.2-mm-diameter pellet with a deuterium-tritium neutron reflector. The Lebedev group would use a 10^5-joule laser incident on a pellet 0.1 mm in diameter, which would cause the density to increase by a factor of 100. (Compare these lasers with the 10^5–10^6 joules suggested by some laser-fusion proponents.)

A critical mass of about 10^{-2} grams would be expected, Askar'yan and his collaborators say. If one assumes a 10% efficiency, the energy released is expected to be 100 MJ, the equivalent of about 50 kg of TNT. Winterberg calculates a compression of 240 times normal density before the explosion, and a critical mass of about 2×10^{-3} grams (or 0.3 grams for the case in which the pellet has no neutron reflector). The elapsed time for disassembly is about 10^{-9} sec, according to the Winterberg scheme, and 10^{-10} sec, according to the Lebedev scheme.

The neutron reflectors proposed in both papers would be expected to yield more energy, aid in the compression and raise the neutron yield. Winterberg specifically proposes a deuterium–tritium neutron reflector for the additional release of thermonuclear energy.

Winterberg suggests that the scheme might be useful as a small fission power plant, for a combined fission–fusion power plant (a safe breeder reactor) or for space propulsion.

One observer believes a more likely application is for research. The very high intensity, very short burst of neutrons might be used for materials studies or neutron-diffraction cross sections, for example.

The Soviet group proposes using the idea to make a linear accelerator. The pellet would be in a magnetic field and as it is compressed, the field cannot diffuse through the pellet. Because there is motion across the field lines, an electric field is produced that is proportional to the rate of change of the magnetic field. Askar'yan and his colleagues say that one could obtain 1 GeV/cm of acceleration. (The superconducting linear accelerator being constructed at Stanford was originally expected to obtain 10 MeV/meter.) Although the intensity from the Soviet device would be very small, the scheme might be useful for making a very concentrated beam of particles, possibly several hundreds of GeV in energy, with a very small device (capable of producing either electrons or protons), according to one accelerator expert.

Another possibility discussed by the Lebedev group is to use the compression to trap the magnetic field, producing fields as high as 10^9 gauss. Typical experiments using explosives for producing magnetic fields have yielded 20 MG. —GBL

References

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in brief

The Joint Institute for Laboratory Astrophysics, a collaboration of the Univ. of Colorado and NBS, has received $380 000 from the NSF Physics Section as funding for the first year of a three-year grant recently authorized by the National Science Board. This is the first NSF low-energy atomic physics block grant. □