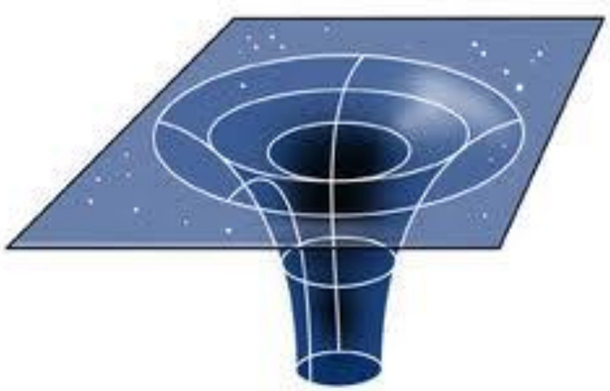


Bermuda Triangles of Space

How the public first met black holes

Marcia Bartusiak – MIT

John Archibald Wheeler

“Well, after I used that phrase four or five times, somebody in the audience said, ‘Why don’t you call it a black hole?’ So I adopted that.”

Interview with Wheeler, 1998

John Archibald Wheeler

AMERICAN SCIENTIST, *56*, **1**, pp. 1–20, 1968

AMERICAN SCIENTIST

SPRING · 1968

OUR UNIVERSE: THE KNOWN AND THE UNKNOWN*

By JOHN ARCHIBALD WHEELER

WHAT KIND of a universe do we live in? A strange one, yes. But where does the strangeness mostly lie? In the seen? Or in the unseen? Shall we fix our attention on the billiard balls as they now bat about the billiard table? Or shall we ask how the game began, and how it will end?

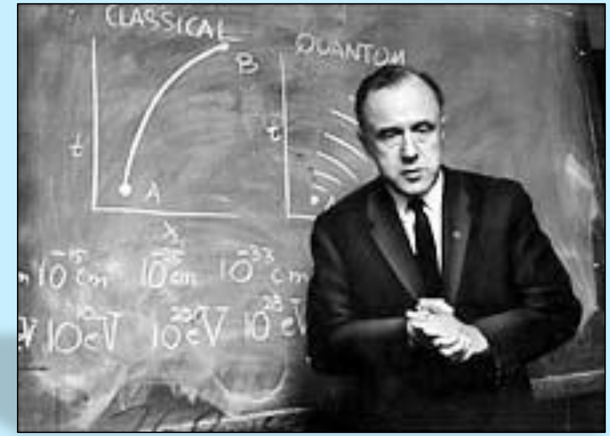
Who will not choose first to look about a little at the game? If then deeper questions come to mind, who will stop our asking them?

Our universe is incomparably more interesting than any play at billiards. The formation of new stars and the explosion of old stars and the greatest variety of events, gigantic in scale and in energy, outrival the most gorgeous fireworks explosion that anyone could imagine in his wildest dreams.

A Famous Supernova

Take up the telescope and turn it on the Crab Nebula. There was no Crab Nebula a thousand years ago. At that time astronomy was at a low level in Europe. Not so in China. There astronomers regularly swept the skies and recorded their observations. In July 1054 they reported a new star. It grew in brightness from day to day. In a few days it outshone every star in the firmament. Then it sank in brilliance, falling off in intensity from week to week. At each date the nova, or supernova as we more appropriately call it, could be compared with neighbor stars for brightness. Out of these comparisons by our Chinese colleagues of long ago one has today constructed a light curve. This light curve is similar to the light curve for supernova events which, through a powerful telescope, one sees from time to time today in far away galaxies. Only the great number of

* The Sigma Xi-Phi Beta Kappa Annual Lecture, American Association for the Advancement of Science, New York, December 29, 1967.



John Archibald Wheeler

AMERICAN SCIENTIST, *56*, **1**, pp. 1–20, 1968

AMERICAN SCIENTIST

SPRING · 1968

OUR UNIVERSE: THE KNOWN AND THE UNKNOWN*

By JOHN ARCHIBALD WHEELER

WHAT KIND of a universe do we live in? A strange one, yes. But where does the strangeness mostly lie? In the seen? Or in the unseen? Shall we fix our attention on the billiard balls as they now bat about the billiard table? Or shall we ask how the game began, and how it will end?

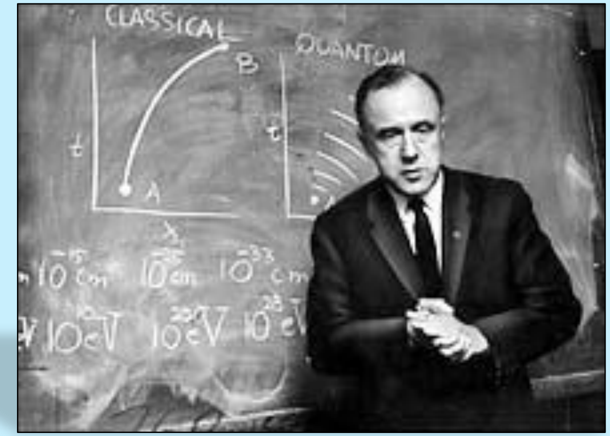
Who will not choose first to look about a little at the game? If then deeper questions come to mind, who will stop our asking them?

Our universe is incomparably more interesting than any play at billiards. The formation of new stars and the explosion of old stars and the greatest variety of events, gigantic in scale and in energy, outrival the most gorgeous fireworks explosion that anyone could imagine in his wildest dreams.

A Famous Supernova

Take up the telescope and turn it on the Crab Nebula. There was no Crab Nebula a thousand years ago. At that time astronomy was at a low level in Europe. Not so in China. There astronomers regularly swept the skies and recorded their observations. In July 1054 they reported a new star. It grew in brightness from day to day. In a few days it outshone every star in the firmament. Then it sank in brilliance, falling off in intensity from week to week. At each date the nova, or supernova as we more appropriately call it, could be compared with neighbor stars for brightness. Out of these comparisons by our Chinese colleagues of long ago one has today constructed a light curve. This light curve is similar to the light curve for supernova events which, through a powerful telescope, one sees from time to time today in far away galaxies. Only the great number of

* The Sigma Xi-Phi Beta Kappa Annual Lecture, American Association for the Advancement of Science, New York, December 29, 1967.



John Archibald Wheeler

The Black Hole

If gravitational collapse is as inescapable in a star as geometrodynamics is inescapable in the universe, then what would be the appearance of the collapsing core if it could be seen from afar without the interference of the supervening envelope? The hot core material is brilliant and at first it shines strongly into the telescope of the observer. However, by reason of its faster and faster infall it moves away from the observer more and more rapidly. The light is shifted to the red. It becomes dimmer millisecond by millisecond, and in less than a second too dark to

see. What was once the core of a star is no longer visible. The core like the Cheshire cat fades from view. One leaves behind only its grin, the other, only its gravitational attraction. Gravitational attraction, yes; light, no. No more than light do any particles emerge. Moreover, light and particles incident from outside emerge and go down the black hole only to add to its mass and increase its gravitational attraction. Has the black hole a size? In one way, yes; in another way, no. There is nothing to look at. One could of course imagine thrusting a meter stick toward the center of attraction until it "touched base." However the powerful tidal forces will tear apart that object and every other object. No conventional measurement of the dimensions is possible. Even to speak about the dimensions of the object in any conventional sense is out of the question. However a light ray can be shot at the black hole, not straight on, but directed far enough off center to one side or the other just barely to escape capture down the black hole—to emerge eventually into a faraway detector of photons. The "diameter" of the black hole as defined in this way is of the order of 10 km, the precise value depending on the mass of the core that underwent collapse. These are the long-known predictions of standard long-established theory.

AMERICAN SCIENTIST, *56*, **1**, pp. 1–20, 1968

AMERICAN SCIENTIST

SPRING · 1968

OUR UNIVERSE: THE KNOWN AND THE UNKNOWN*

By JOHN ARCHIBALD WHEELER

WHAT KIND of a universe do we live in? A strange one, yes. But where does the strangeness mostly lie? In the seen? Or in the unseen? Shall we fix our attention on the billiard balls as they now bat about the billiard table? Or shall we ask how the game began, and how it will end?

Who will not choose first to look about a little at the game? If then deeper questions come to mind, who will stop our asking them?

Our universe is incomparably more interesting than any play at billiards. The formation of new stars and the explosion of old stars and the greatest variety of events, gigantic in scale and in energy, outrival the most gorgeous fireworks explosion that anyone could imagine in his wildest dreams.

A Famous Supernova

Take up the telescope and turn it on the Crab Nebula. There was no Crab Nebula a thousand years ago. At that time astronomy was at a low level in Europe. Not so in China. There astronomers regularly swept the skies and recorded their observations. In July 1054 they reported a new star. It grew in brightness from day to day. In a few days it outshone every star in the firmament. Then it sank in brilliance, falling off in intensity from week to week. At each date the nova, or supernova as we more appropriately call it, could be compared with neighbor stars for brightness. Out of these comparisons by our Chinese colleagues of long ago one has today constructed a light curve. This light curve is similar to the light curve for supernova events which, through a powerful telescope, one sees from time to time today in far away galaxies. Only the great number of

* The Sigma Xi-Phi Beta Kappa Annual Lecture, American Association for the Advancement of Science, New York, December 29, 1967.

John Archibald Wheeler

The Black Hole

If gravitational collapse is as inescapable in a star as geometrodynamics is inescapable in the universe, then what would be the appearance of the collapsing core if it could be seen from afar without the interference of the supervening envelope? The hot core material is brilliant and at first it shines strongly into the telescope of the observer. However, by reason of its faster and faster infall it moves away from the observer more and more rapidly. The light is shifted to the red. It becomes dimmer millisecond by millisecond, and in less than a second too dark to

see. What was once the core of a star is no longer visible. The core like the Cheshire cat fades from view. One leaves behind only its grin, the other, only its gravitational attraction. Gravitational attraction, yes; light, no. No more than light do any particles emerge. Moreover, light and particles incident from outside emerge and go down the black hole only to add to its mass and increase its gravitational attraction. Has the black hole a size? In one way, yes; in another way, no. There is nothing to look at. One could of course imagine thrusting a meter stick toward the center of attraction until it "touched base." However the powerful tidal forces will tear apart that object and every other object. No conventional measurement of the dimensions is possible. Even to speak about the dimensions of the object in any conventional sense is out of the question. However a light ray can be shot at the black hole, not straight on, but directed far enough off center to one side or the other just barely to escape capture down the black hole—to emerge eventually into a faraway detector of photons. The "diameter" of the black hole as defined in this way is of the order of 10 km, the precise value depending on the mass of the core that underwent collapse. These are the long-known predictions of standard long-established theory.

Chicago Tribune

Weigh Possibility of Gravity Collapse

[Chicago Tribune Press Service]

New York, Dec. 30—The scientists who harnessed part of the universe to make nuclear bombs are now tinkering with an even mightier force believed to exist in space.

This is the enormous force of gravitational collapse which theoretically can swallow up mighty stars and turn them into nothing.

Talk of this gigantic force has opened the door to speculation about a gravity bomb that could swallow the earth. But scientists who are working in this area are quick to say that it is probably impossible to build such a weapon.

Calls It Impossible

"There is no way in the world to make such a bomb," said Dr. John Archibald Wheeler of Princeton university, who worked on the development of the atomic bomb.

The task of building such a bomb would be equivalent to placing one million elephants on the head of a pin at the same time.

Gravitational collapse is believed to occur when an object such as a star is forced by outside pressures to condense. As it becomes smaller the matter inside becomes more tightly packed and the gravitational forces become stronger and stronger.

Overwhelms Other Forces

At one point the force of gravity becomes so great that it overwhelms all other forces and hugs all the matter toward the core in a big bone-crushing squeeze.

This force is self-accelerating. As the matter condenses the gravitational force becomes more powerful. It can squeeze tons of solid matter into the size of one atom.

Scientists have calculated that a star much bigger than our sun that undergoes gravitational collapse could be reduced in diameter from millions of miles to 3.5 miles.

Leaves "Black Hole"

But the most intriguing aspect of this force is that it creates a nothingness where once a giant star shone.

This is referred to as the "black hole" in space effect. It occurs because no energy, not even light, can escape from the immense force created by gravitational collapse.

Reporting at the 134th annual meeting of the American Association for the Advancement of Science, Dr. Wheeler said that he and other astrophysicists are searching the heavens for evidence of the black holes.

Little Known About Force

At this point little is known about the force involved in gravitational collapse. It is perhaps similar to the period at the earlier part of this decade when such men as Lord Rutherford and Albert Einstein predicted that nuclear energy was a scientific curiosity that would never have any practical application.

Dr. Wheeler suggested that perhaps the explanation that produced the Crab nebula in 1054 was caused by gravitational collapse.

In this case some of the energy generated during the one second it takes for a star to collapse could have shot off some of the debris of the star into the spiral arms of the nebula.

Recalls Bomb Test

Scientists are now trying to understand the gravitational collapse effect just as they succeeded in mastering nuclear energy, which until 1942 was an event different from anything in human experience.

"A bit of star was first brought down to earth at Alamagordo, N. M., in the atomic bomb test in July, 1945," Dr. Wheeler said.

"No event in history ever gave a more dramatic example of mans' understanding of nature but there are still some aspects of nature we have yet to comprehend," he added.

One of the reasons that some scientists believe there may be many black holes in space is the fact that all the matter that has been calculated to exist in the universe is only one-tenth to one one-hundredth of the matter that Einstein predicted.

Dr. Wheeler said that it may be that much of this missing matter may exist in these black holes.

Chicago Tribune 31 Dec 1967

Chicago Tribune

Weigh Possibility of Gravity Collapse

[Chicago Tribune Press Service]

New York, Dec. 30—The scientists who harnessed part of the universe to make nuclear bombs are now tinkering with an even mightier force believed to exist in space.

This is the enormous force of gravitational collapse which theoretically can swallow up mighty stars and turn them into nothing.

Talk of this gigantic force has opened the door to speculation about a gravity bomb that could swallow the earth. But scientists who are working in this area are quick to say that it is probably impossible to build such a weapon.

Calls It Impossible

"There is no way in the world to make such a bomb," said Dr. John Archibald Wheeler of Princeton university, who worked on the development of the atomic bomb.

The task of building such a bomb would be equivalent to placing one million elephants on the head of a pin at the same time.

Gravitational collapse is believed to occur when an object such as a star is forced by outside pressures to condense. As it becomes smaller the matter inside becomes more tightly packed and the gravitational forces become stronger and stronger.

Overwhelms Other Forces

At one point the force of gravity becomes so great that it overwhelms all other forces and hugs all the matter toward the core in a big bone-crushing squeeze.

This force is self-accelerating. As the matter condenses the gravitational force becomes more powerful. It can squeeze tons of solid matter into the size of one atom.

Scientists have calculated that a star much bigger than our sun that undergoes gravitational collapse could be reduced in diameter from millions of miles to 3.5 miles.

Leaves "Black Hole"

But the most intriguing aspect of this force is that it creates a nothingness where once a giant star shone.

This is referred to as the "black hole" in space effect. It occurs because no energy, not even light, can escape from the immense force created by gravitational collapse.

Reporting at the 134th annual meeting of the American Association for the Advancement of Science, Dr. Wheeler said that he and other astrophysicists are searching the heavens for evidence of the black holes.

Little Known About Force

At this point little is known about the force involved in gravitational collapse. It is perhaps similar to the period at the earlier part of this decade when such men as Lord Rutherford and Albert Einstein predicted that nuclear energy was a scientific curiosity that would never have any practical application.

Dr. Wheeler suggested that perhaps the explanation that produced the Crab nebula in 1054 was caused by gravitational collapse.

In this case some of the energy generated during the one second it takes for a star to collapse could have shot off some of the debris of the star into the spiral arms of the nebula.

Recalls Bomb Test

Scientists are now trying to understand the gravitational collapse effect just as they succeeded in mastering nuclear energy, which until 1942 was an event different from anything in human experience.

"A bit of star was first brought down to earth at Alamagordo, N. M., in the atomic bomb test in July, 1945," Dr. Wheeler said.

"No event in history ever gave a more dramatic example of mans' understanding of nature but there are still some aspects of nature we have yet to comprehend," he added.

One of the reasons that some scientists believe there may be many black holes in space is the fact that all the matter that has been calculated to exist in the universe is only one-tenth to one one-hundredth of the matter that Einstein predicted.

Dr. Wheeler said that it may be that much of this missing matter may exist in these black holes.

Chicago Tribune 31 Dec 1967

Chicago Tribune

Weigh Possibility of Gravity Collapse

[Chicago Tribune Press Service]

New York, Dec. 30—The scientists who harnessed part of the universe to make nuclear bombs are now tinkering with an even mightier force believed to exist in space.

This is the enormous force of gravitational collapse which theoretically can swallow up mighty stars and turn them into nothing.

Talk of this gigantic force has opened the door to speculation about a gravity bomb that could swallow the earth. But scientists who are working in this area are quick to say that it is probably impossible to build such a weapon.

Calls It Impossible

"There is no way in the world to make such a bomb," said Dr. John Archibald Wheeler of Princeton university, who worked on the development of the atomic bomb.

The task of building such a bomb would be equivalent to placing one million elephants on the head of a pin at the same time.

Gravitational collapse is believed to occur when an object such as a star is forced by outside pressures to condense. As it becomes smaller the matter inside becomes more tightly packed and the gravitational forces become stronger and stronger.

Overwhelms Other Forces

At one point the force of gravity becomes so great that it overwhelms all other forces and hugs all the matter toward the core in a big bone-crushing squeeze.

This force is self-accelerating. As the matter condenses the gravitational force becomes more powerful. It can squeeze tons of solid matter into the size of one atom.

Scientists have calculated that a star much bigger than our sun that undergoes gravitational collapse could be reduced in diameter from millions of miles to 3.5 miles.

Leaves "Black Hole"

But the most intriguing aspect of this force is that it creates a nothingness where once a giant star shone.

This is referred to as the "black hole" in space effect. It occurs because no energy, not even light, can escape from the immense force created by gravitational collapse.

Reporting at the 134th annual meeting of the American Association for the Advancement of Science, Dr. Wheeler said that he and other astrophysicists are searching the heavens for evidence of the black holes.

Little Known About Force

At this point little is known about the force involved in gravitational collapse. It is perhaps similar to the period at the earlier part of this decade when such men as Lord Rutherford and Albert Einstein predicted that nuclear energy was a scientific curiosity that would never have any practical application.

Dr. Wheeler suggested that perhaps the explanation that produced the Crab nebula in 1054 was caused by gravitational collapse.

In this case some of the energy generated during the one second it takes for a star to collapse could have shot off some of the debris of the star into the spiral arms of the nebula.

Recalls Bomb Test

Scientists are now trying to understand the gravitational collapse effect just as they succeeded in mastering nuclear energy, which until 1942 was an event different from anything in human experience.

"A bit of star was first brought down to earth at Alamagordo, N. M., in the atomic bomb test in July, 1945," Dr. Wheeler said.

"No event in history ever gave a more dramatic example of mans' understanding of nature but there are still some aspects of nature we have yet to comprehend," he added.

One of the reasons that some scientists believe there may be many black holes in space is the fact that all the matter that has been calculated to exist in the universe is only one-tenth to one one-hundredth of the matter that Einstein predicted.

Dr. Wheeler said that it may be that much of this missing matter may exist in these black holes.

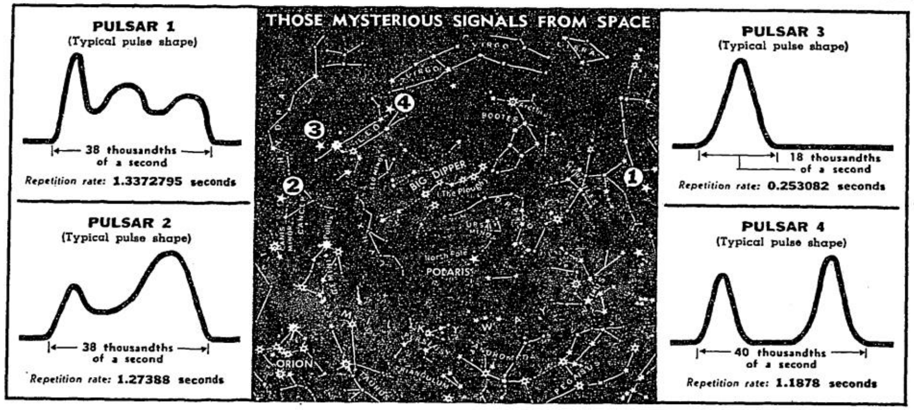
Chicago Tribune 31 Dec 1967

Science

New York Times 14 April 1968

Pulsations From Space

There are more things in heaven and earth, Horatio, Than are dreamt of in your philosophy.



Observations with the radio telescope at Arecibo, P. R., have shown that three of the "beeping" objects recently discovered (map) have much in common. They are known as Pulsar 1, Pulsar 2 and Pulsar 4. All repeat their pulses at intervals of slightly more than one second and each pulse lasts from 38 to 40 thousandths of a second. Each also has its characteristic pulse shape (single, double or triple) when diplayed on an oscilloscope. Pulsar 3 differs from the others. All may be neutron stars.

Those words, with which Hamlet reassured his friend after the ghostly appearance of Hamlet's father, were equally applicable last week to laymen who contemplated the full implications of the strange, newly discovered pulsars. It appeared that they are either manifestations of intelligent life in other worlds, or—more likely—provide an initial peek into an awesome realm of knowledge.

The discovery that the rhythmic radio pulsations of the pulsars are, in fact, signals from other intelligent beings would be enormously exciting to people everywhere. But confirmation of the proposal, discussed at a meeting in Washington last week, that they are neutron stars, would imply that mankind may be able to penetrate what had been considered a forbidden sanctuary.

'Black Hole'

As recently as last December a leading theoretical physicist, Dr. John A. Wheeler of Princeton, predicted that it would never be possible to make direct observations of a neutron star, or its hypothetical cousin, the "black hole," where all physical laws seem to run amok. A black hole is a star collapsing into something infinitely small and infinitely dense.

An understanding of what happens under these far-out conditions might enable man to answer such basic questions as whether the universe began as nothing and will end as nothing. In the neutron stars and black holes we may find the long-sought "missing" matter of the universe—making up 90 per cent or more of it.

The four known pulsars were discovered last year by British radio astronomers at Cambridge University.

At a meeting last week of the American branch of the International Scientific Radio Union, Dr. Frank D. Drake, director of the Arecibo Ionospheric Observatory in Puerto Rico, described observations of the four known pulsars made with his 1,000-foot-wide antenna, the largest such receiver in the world.

The extraordinary uniformity of the pulse rates would make them ideal as navigation beacons for civilizations capable of space travel, he said. Likewise, the peculiar variations in pulse strength, in the pulses as observed at different wavelengths, and in the various components of each pulse (many are triplets) all suggest intelligent signaling.

Nevertheless, he said, an intelligent origin seems very unlikely because the distribution of energy, across the radio spectrum, is what one would expect from a natural source. It would be illogical and inefficient for signaling.

Dr. Thomas Gold, director of Cornell University's Center for Radiophysics and Space Research, which operates the Arecibo observatory, then outlined the argument that the pulsars are, in fact, fast-spinning neutron stars. The latter consist of a tight ball of neutrons, the electrically neutral particles of the atomic nucleus.

A normal atom can be likened to the solar system in that it consists largely of open space with a tiny, very dense nucleus in its center and electrons flying about it at various distances. In a neutron star there is no such space. It is believed to form when a star considerably larger than our sun (which is 864,000 miles in diameter) burns up its fuel and collapses into an object 10 miles wide. With none of the thermonuclear reactions that make a star shine, such a star would be invisible at any great distance.

Dr. Gold noted that three of the most perplexing features of the pulsars could be explained if they were neutron stars: their rigid pulse rate, the unusual tempo of that rate, and the absence of obvious visible sources for the emissions.

There are many highly rhythmic phenomena in astronomy, such as the spin of the earth and the movements of two stars around one another. But rhythms of a second or less are difficult to explain except in terms of small, extremely dense bodies—namely neutron stars.

At the meeting both Dr. Gold and Dr. Alexander J. Dessler of Rice University argued in favor of spinning neutron stars whose intense magnetic fields would "aim" the emissions into space. This signal beam would sweep the earth once with each revolution.

At the last annual meeting of the American Association for the Advancement of Science Dr. Wheeler summarized current theory concerning the neutron stars and the "black holes."

When the nuclear fuel of a star has been exhausted, the outward pressure of heat from its core diminishes and the star begins to contract.

If the star is several times more massive than the sun the weight of its own overlying material is sufficient to crush its internal structure. The star's collapse proceeds at catastrophic speed—within a fraction of a second—and the resulting energy blows off the outer part of the star in a supernova, so brilliant that it may be visible in daylight for days or weeks.

Collapsing Star

It is believed that the remaining core contracts into a superdense body of neutrons which is very hot for a short period, but then cools into a body too dim for observation.

The black hole is formed when the original star is very large. The pressures on its core during the collapse are so great that, instead of exploding, it keeps on collapsing with ever increasing speed. The pressure becomes so great that even neutrons cannot withstand it. They, too, collapse. But into what?

Dr. Wheeler spoke, in his lecture of all atomic particles being "constructed out of space." They could thus be squeezed back into space.

The neutron stars and black holes could resolve the "missing matter" dilemma. Although the universe is obviously expanding, it seems to be held together by the gravitational attraction of all its parts. Yet the extent of this gravitational "glue" implies the existence of from 10 to 100 times more material in the universe than is evident in terms of stars, galaxies, dust clouds and so forth. Perhaps the neutron stars and black holes make up the difference.

Some have proposed that the entire universe may be destined to collapse into an all-into-nothing hole. We cannot hope to observe a black hole, since neither light nor anything else can escape its gravity to tell us what goes on there.

If, however, through the pulsars we achieve an insight into neutron stars, we will be able to explore conditions bordering on those of the black hole.

—WALTER SULLIVAN

New York Times

~ 1969-70

P. Kafka (Max-Planck-Institut für Physik und Astrophysik München): Discussion of Possible Sources of Gravitational Radiation.

WEBER (1969) reported the detection of gravitational radiation on a high level of significance. Radiation seems to arrive in pulses of duration less than 0.4 sec. The frequency of observation was 1660 Hz. The energy arriving over the pulse in a bandwidth $\Delta\omega \approx 0.1$ was of the order of 10^4 erg cm^{-2}. Hence, if a flat spectrum is assumed up to a cut-off at or beyond the frequency of observation, the total energy per cm^2 in each pulse was $> 10^9$ ergs. A source at distance D (kiloparsecs) must have emitted

$$E > 10^{53} \times D^2 \text{ ergs.} \quad (1)$$

Whereas the observation of about one such pulse per century or even per year might be expected at the present state of knowledge, WEBER's observations indicate a number of about hundred per year. This poses severe problems.

A strong pulse of gravitational radiation is expected only when a configuration of mass m comes close to its Schwarzschild radius $r_s = 2\,\mathrm{Gm}/c^2 \approx 3\,\mathrm{m/m_\odot}$ km, and its quadrupole and/or higher moments change rapidly. A critical surface of approximate extent r_s will exist in any relativistic theory of gravitation (cf. TRAUTMAN, 1965), also for asymmetric configurations.

The following situations are possible sources for pulses of gravitational radiation:
(1) Gravitational collapse of a rotating star towards a neutron star. In this case a pulse at roughly 1 kHz, lasting about 1 sec, with a total energy of the order of 10^{52} ergs ($\lesssim 1/2\,\%$ of the stellar rest-mass energy) is expected, according to recent work at Caltech (cf. BURKE and THORNE, 1969). It is due to vibrational modes excited in the collapse.

(2) Hypothetical transitions in the state of a neutron star in which asymmetric vibrations may be excited. Similar processes have been proposed as a possible cause for the sudden decrease in the period of the pulsar PSR 0833–45 between February 24th and March 3rd 1969. Such "neutron-star-quakes" might emit a gravitational pulse similar to that in case (1) but with a smaller total energy.

(3) Asymmetric collapse towards a "black hole" (as a collapsing object is called in the state where gravitational redshift and capture make all types of radiation fade away for a distant observer, and only the stationary gravitational field remains). In such events one can expect a pulse of gravitational radiation. Its duration will be roughly $\tau \gtrsim r_s/c \approx 10^{-5}\,m/m_\odot$ [sec], the high-frequency cut-off will lie near $\nu \approx \tau^{-1}$, and the total energy may nearly reach the order of $mc^2 \approx 10^{54.3}\,m/m_\odot$ [ergs].

GRAVITATIONAL COLLAPSE WITH ASYMMETRIES

V. de la Cruz
Physics Department, University of Saskatchewan, Regina, Saskatchewan, Canada

and

J. E. Chase and W. Israel
Mathematics Department, University of Alberta, Edmonton, Alberta, Canada
(Received 2 December 1969)

Two idealized collapse models, involving a magnetic dipole and a gravitational quadrupole, are analyzed, treating departures from sphericity as small perturbations. Radiative leakage (largely downwards through the Schwarzschild radius) causes externally observable asymmetries to decay to zero in an oscillatory fashion, with a period of the order of the Schwarzschild characteristic time $2Gm/c^3$. These results have significant consequences for astrophysics; they imply in particular that a "black hole" cannot be a source of synchrotron radiation.

Every static nonspherical perturbation of Schwarzschild's exterior field due to gravitational or electromagnetic sources within the stationary lightlike surface $g_{00} = 0$ becomes singular on this surface.[1-3] Stationary perturbations of Kerr's rotating solution appear to have a similar property.[4] Assuming these results to be applicable to the asymptotically stationary exterior field of a collapsing star, one is led to conjecture that all externally detectable asymmetries,[1] including magnetic fields,[2] must somehow decay, leaving behind Schwarzschild's vacuum field (or, in the case of nonvanishing angular momentum, Kerr's field) as the sole external manifestation of the collapsed object.

To examine these questions, we have carried out a dynamical analysis of two idealized collapse models, one involving a magnetic dipole, the other a gravitational quadrupole. Our results support the foregoing conjecture and reveal the decay mechanism to be a rapid radiative leakage of the asymmetric perturbing field, largely downwards through the event horizon.

We cast the Schwarzschild metric into the form $(ds^2)_{\mathrm{Schw}} = \alpha dx dy + r^2 d\Omega^2$, where $\alpha = 1 - 1/r$, and the retarded and advanced time coordinates $-x, y$ are related to the standard Schwarzschild coordinates by $x, y = (r-1) + \ln(r-1) \mp t$. Lengths are measured in units of the Schwarzschild radius: $2m = 1$.

Both of our models can be considered as linearly perturbed variations of the following basic situation (Fig. 1). A thin, hollow spherical shell of mass $m = \frac{1}{2}$ is initially static with radius $R_0 \gg 1$; at time $t = -\frac{1}{2}x_0 \equiv -(R_0-1) - \ln(R_0-1)$, it suddenly begins to collapse at the speed of light (history of surface $y = 0$). (This model, adopted for mathematical simplicity, is highly artificial from an astrophysicist's point of view, but does not violate any of the principles of relativity theory. Moreover, our main interest is in the asymptotic behavior of the external field as $t \to \infty$, and we do not expect this to depend too sensitively on the precise structure of the source or the initial conditions.)

In our first ("magnetic collapse") model, we suppose a static magnetic dipole of moment μ placed at the center of the shell. (It is assumed that $\mu^2 \ll 1$, which means gravitational effects of the magnetic energy density can be neglected for $r \geq 1$.) Our second ("quadrupole") model assumes a weak gravitational quadrupole of moment q superimposed on the spherical background field and caused by unevenesses in the surface density of the shell.

Since news of the onset of collapse cannot reach the interior ahead of the shell itself, the

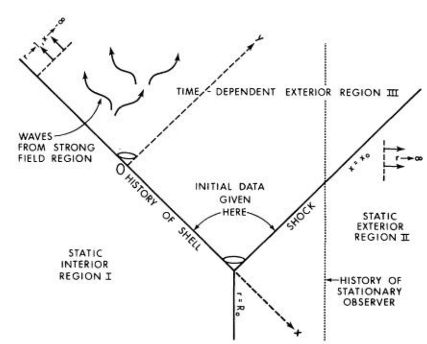


FIG. 1. Space-time diagram for collapsing shell model.

~ 1969-70

P. Kafka (Max-Planck-Institut für Physik und Astrophysik München): Discussion of Possible Sources of Gravitational Radiation.

Weber (1969) reported the detection of gravitational radiation on a high level of significance. Radiation seems to arrive in pulses of duration less than 0.4 sec. The frequency of observation was 1660 Hz. The energy arriving over the pulse in a bandwidth $\Delta\omega \approx 0.1$ was of the order of 10^4 erg cm^{-2}. Hence, if a flat spectrum is assumed up to a cut-off at or beyond the frequency of observation, the total energy per cm^2 in each pulse was $>10^9$ ergs. A source at distance D (kiloparsecs) must have emitted

$$E > 10^{53} \times D^2 \text{ ergs.} \quad (1)$$

Whereas the observation of about one such pulse per century or even per year might be expected at the present state of knowledge, Weber's observations indicate a number of about hundred per year. This poses severe problems.

A strong pulse of gravitational radiation is expected only when a configuration of mass m comes close to its Schwarzschild radius $r_s = 2\ \mathrm{Gm/c^2} \approx 3\ \mathrm{m/m_\odot}$ km, and its quadrupole and/or higher moments change rapidly. A critical surface of approximate extent r_s will exist in any relativistic theory of gravitation (cf. Trautman, 1965), also for asymmetric configurations.

The following situations are possible sources for pulses of gravitational radiation: (1) Gravitational collapse of a rotating star towards a neutron star. In this case a pulse at roughly 1 kHz, lasting about 1 sec, with a total energy of the order of 10^{52} ergs ($\lesssim 1/2$% of the stellar rest-mass energy) is expected, according to recent work at Caltech (cf. Burke and Thorne, 1969). It is due to vibrational modes excited in the collapse.

(2) Hypothetical transitions in the state of a neutron star in which asymmetric vibrations may be excited. Similar processes have been proposed as a possible cause for the sudden decrease in the period of the pulsar PSR 0833–45 between February 24th and March 3rd 1969. Such "neutron-star-quakes" might emit a gravitational pulse similar to that in case (1) but with a smaller total energy.

(3) Asymmetric collapse towards a "black hole" (as a collapsing object is called in the state where gravitational redshift and capture make all types of radiation fade away for a distant observer, and only the stationary gravitational field remains). In such events one can expect a pulse of gravitational radiation. Its duration will be roughly $\tau \gtrsim r_s/c \approx 10^{-5}\ m/m_\odot$ [sec], the high-frequency cut-off will lie near $\nu \approx \tau^{-1}$, and the total energy may nearly reach the order of $mc^2 \approx 10^{54.3}\ m/m_\odot$ [ergs].

GRAVITATIONAL COLLAPSE WITH ASYMMETRIES

V. de la Cruz
Physics Department, University of Saskatchewan, Regina, Saskatchewan, Canada

and

J. E. Chase and W. Israel
Mathematics Department, University of Alberta, Edmonton, Alberta, Canada

(Received 2 December 1969)

Two idealized collapse models, involving a magnetic dipole and a gravitational quadrupole, are analyzed, treating departures from sphericity as small perturbations. Radiative leakage (largely downwards through the Schwarzschild radius) causes externally observable asymmetries to decay to zero in an oscillatory fashion, with a period of the order of the Schwarzschild characteristic time $2Gm/c^3$. These results have significant consequences for astrophysics; they imply in particular that a "black hole" cannot be a source of synchrotron radiation.

Every static nonspherical perturbation of Schwarzschild's exterior field due to gravitational or electromagnetic sources within the stationary lightlike surface $g_{00} = 0$ becomes singular on this surface.[1-3] Stationary perturbations of Kerr's rotating solution appear to have a similar property.[4] Assuming these results to be applicable to the asymptotically stationary exterior field of a collapsing star, one is led to conjecture that all externally detectable asymmetries,[1] including magnetic fields,[2] must somehow decay, leaving behind Schwarzschild's vacuum field (or, in the case of nonvanishing angular momentum, Kerr's field) as the sole external manifestation of the collapsed object.

To examine these questions, we have carried out a dynamical analysis of two idealized collapse models, one involving a magnetic dipole, the other a gravitational quadrupole. Our results support the foregoing conjecture and reveal the decay mechanism to be a rapid radiative leakage of the asymmetric perturbing field, largely downwards through the event horizon.

We cast the Schwarzschild metric into the form $(ds^2)_{\mathrm{Schw}} = \alpha dx dy + r^2 d\Omega^2$, where $\alpha = 1 - 1/r$, and the retarded and advanced time coordinates $-x, y$ are related to the standard Schwarzschild coordinates by $x, y = (r-1) + \ln(r-1) \mp t$. Lengths are measured in units of the Schwarzschild radius: $2m = 1$.

Both of our models can be considered as linearly perturbed variations of the following basic situation (Fig. 1). A thin, hollow spherical shell of mass $m = \frac{1}{2}$ is initially static with radius $R_0 \gg 1$; at time $t = -\frac{1}{2}x_0 \equiv -(R_0 - 1) - \ln(R_0 - 1)$, it suddenly begins to collapse at the speed of light (history of surface $y = 0$). (This model, adopted for mathematical simplicity, is highly artificial from an astrophysicist's point of view, but does not violate any of the principles of relativity theory. Moreover, our main interest is in the asymptotic behavior of the external field as $t \to \infty$, and we do not expect this to depend too sensitively on the precise structure of the source or the initial conditions.)

In our first ("magnetic collapse") model, we suppose a static magnetic dipole of moment μ placed at the center of the shell. (It is assumed that $\mu^2 \ll 1$, which means gravitational effects of the magnetic energy density can be neglected for $r \geq 1$.) Our second ("quadrupole") model assumes a weak gravitational quadrupole of moment q superimposed on the spherical background field and caused by unevenesses in the surface density of the shell.

Since news of the onset of collapse cannot reach the interior ahead of the shell itself, the

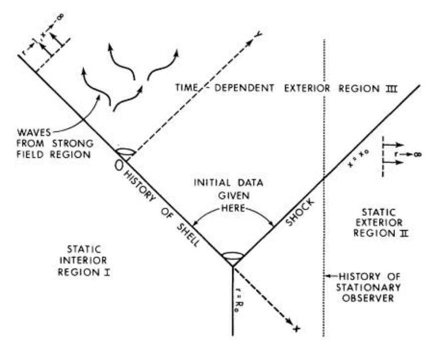
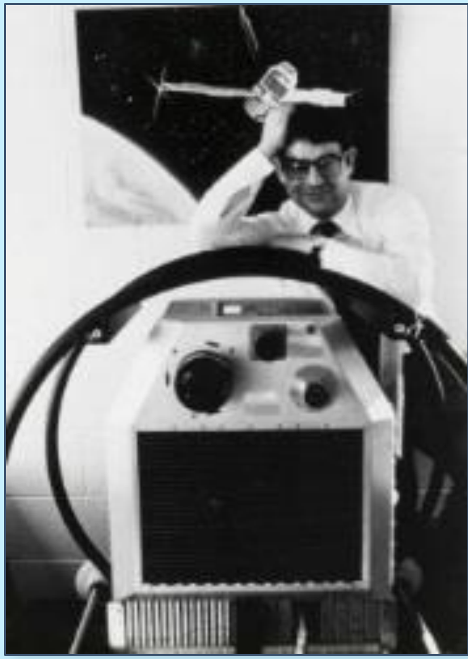
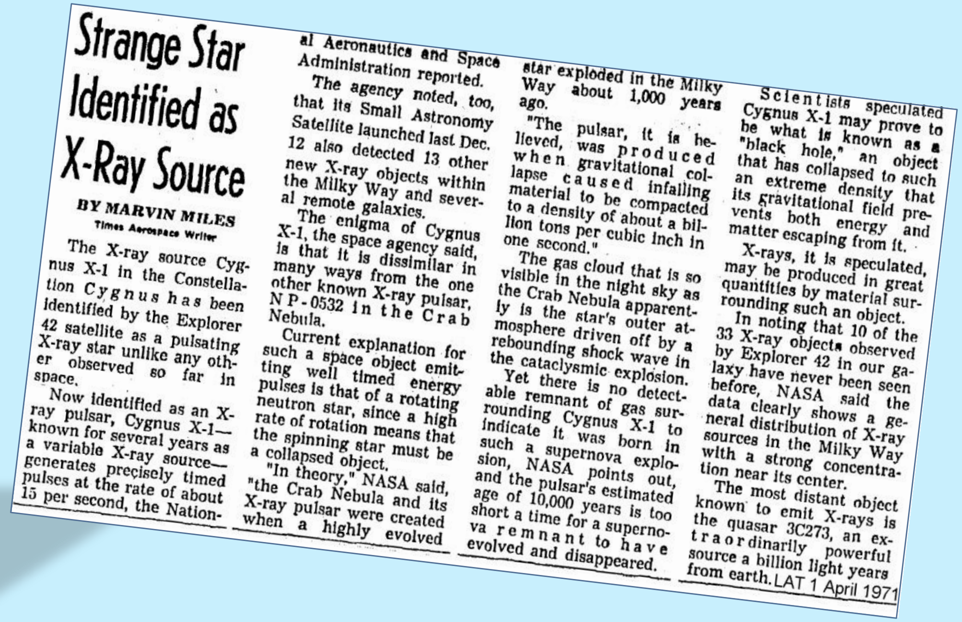


FIG. 1. Space-time diagram for collapsing shell model.

Riccardo Giacconi
and *Uhuru* in 1970



Riccardo Giacconi and *Uhuru* in 1970



Strange Star Identified as X-Ray Source

BY MARVIN MILES
Times Aerospace Writer

The X-ray source Cygnus X-1 in the Constellation Cygnus has been identified by the Explorer 42 satellite as a pulsating X-ray star unlike any other observed so far in space.

Now identified as an X-ray pulsar, Cygnus X-1—known for several years as a variable X-ray source—generates precisely timed pulses at the rate of about 15 per second, the National Aeronautics and Space Administration reported.

The agency noted, too, that its Small Astronomy Satellite launched last Dec. 12 also detected 13 other new X-ray objects within the Milky Way and several remote galaxies.

The enigma of Cygnus X-1, the space agency said, is that it is dissimilar in many ways from the one other known X-ray pulsar, NP-0532 in the Crab Nebula.

Current explanation for such a space object emitting well timed energy pulses is that of a rotating neutron star, since a high rate of rotation means that the spinning star must be a collapsed object.

"In theory," NASA said, "the Crab Nebula and its X-ray pulsar were created when a highly evolved star exploded in the Milky Way about 1,000 years ago.

"The pulsar, it is believed, was produced when gravitational collapse caused infalling material to be compacted to a density of about a billion tons per cubic inch in one second."

The gas cloud that is so visible in the night sky as the Crab Nebula apparently is the star's outer atmosphere driven off by a rebounding shock wave in the cataclysmic explosion.

Yet there is no detectable remnant of gas surrounding Cygnus X-1 to indicate it was born in such a supernova explosion, NASA points out, and the pulsar's estimated age of 10,000 years is too short a time for a supernova remnant to have evolved and disappeared.

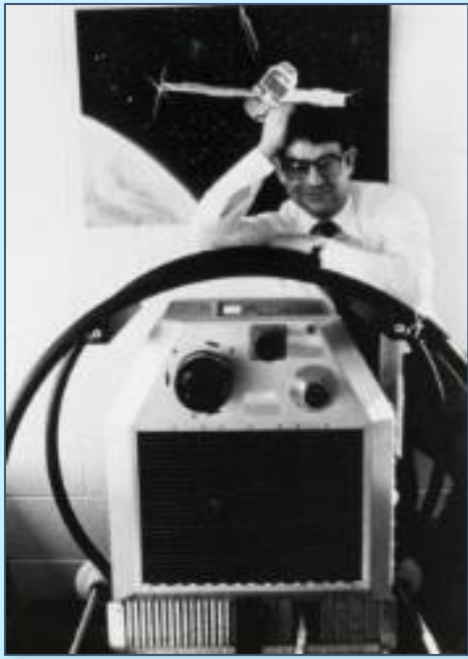
Scientists speculated Cygnus X-1 may prove to be what is known as a "black hole," an object that has collapsed to such an extreme density that its gravitational field prevents both energy and matter escaping from it.

X-rays, it is speculated, may be produced in great quantities by material surrounding such an object.

In noting that 10 of the 33 X-ray objects observed by Explorer 42 in our galaxy have never been seen before, NASA said the data clearly shows a general distribution of X-ray sources in the Milky Way with a strong concentration near its center.

The most distant object known to emit X-rays is the quasar 3C273, an extraordinarily powerful source a billion light years from earth.

LAT 1 April 1971



Riccardo Giacconi and *Uhuru* in 1970

Strange Star Identified as X-Ray Source

BY MARVIN MILES
Times Aerospace Writer

The X-ray source Cygnus X-1 in the Constellation Cygnus has been identified by the Explorer 42 satellite as a pulsating X-ray star unlike any other observed so far in space.

Now identified as an X-ray pulsar, Cygnus X-1 ... known for several years ... a variable X-ray sourc... generates precisely t... pulses at the rate of a... 15 per second, the N...

...al Aeronautics and Space Administ... ...orted.

The a... that its... Satellit... 12 als... new ... the ... al ...

...star exploded in the Milky Way about 1,000 years ago.

...The pulsar, it is be... produced ... col...

Scientists speculated Cygnus X-1 may prove to be what is known as a "black hole," an object that has collapsed to such an extreme density that its gravitational field prevents both energy and ... from it.

...ulated,

US satellite finds new X-ray source

By Victor K. McElheny
Globe Staff

The first X-ray observatory in space, designed and partly built in Cambridge, has discovered a puzzling new pulsating source of X-rays in the heavens.

The discovery, announced yesterday in Baton Rouge, La., could turn out to be the first observation of rays from the neighborhood of or something physicists have called a "black hole" in the universe.

The source, called Cygnus X-1 and found in the constellation Cygnus, is unlike the only previously observed X-ray "pulsar" in the Crab Nebula. That source puts out radio and light pulses like its X-ray pulses, but Cygnus X-1 apparently does not. And the Crab Nebula is the remnant of a huge "supernova" explosion. Cygnus X-1 apparently is not.

The observations of the Cygnus "pulsar" were made March 6 by the US satellite Uhuru or Explorer 42.

The satellite, whose X-ray detectors were designed at American Science and Engineering Inc. near Kendall square, has been circling the equator since Dec. 12, 1970.

The X-rays from the Crab Nebula "pulsar" are assumed to be coming from something physicists have dubbed a "neutron" star, a madly spinning dense hunk of matter less than 10 miles across.

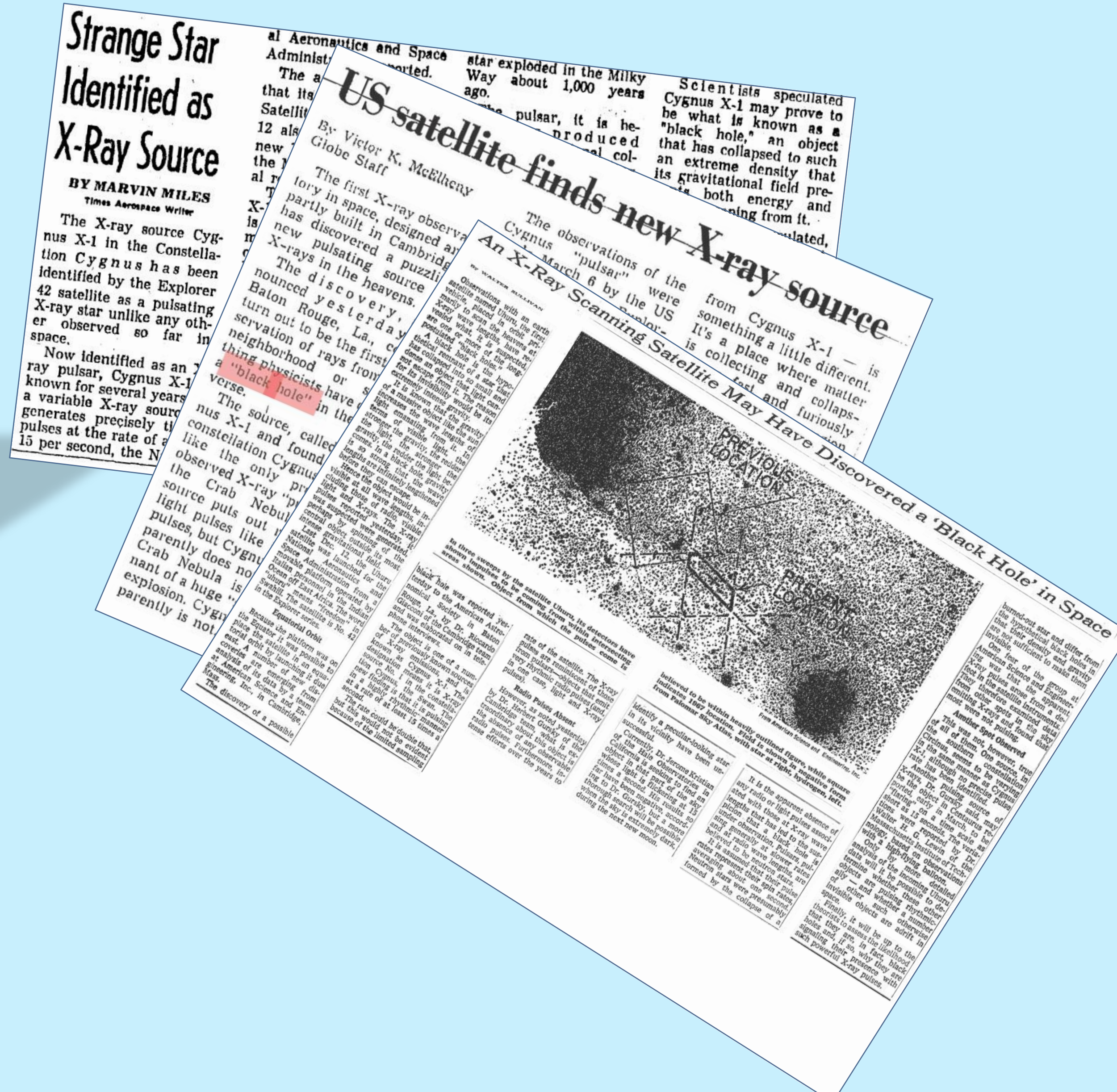
In a neutron star, matter is packed so densely that the material of the Earth would fit into the volume of a hotel ballroom and the whole Sun into the 10-mile diameter.

A black hole—the explanation for the X-rays from Cygnus X-1 — is something a little different. It's a place where matter is collecting and furiously collapsing so fast and into such a dense region that its gravity would prevent any matter—or any telltale energy in the form of light or radio waves or X-rays — from escaping.

But in the immediate neighborhood of a black hole, as matter rushed toward the pit, things might be jumping violently enough to produce a lot of X-rays.

Boston Globe
1 April 1971

Riccardo Giacconi and *Uhuru* in 1970



Strange Star Identified as X-Ray Source

BY MARVIN MILES
Times Aerospace Writer

The X-ray source Cygnus X-1 in the Constellation Cygnus has been identified by the Explorer 42 satellite as a pulsating X-ray star unlike any other observed so far in space.

Now identified as an X-ray pulsar, Cygnus X-1 ... known for several years ... a variable X-ray sourc... generates precisely ... pulses at the rate of a... 15 per second, the N...

...al Aeronautics and Space Administ... reported.

...star exploded in the Milky Way about 1,000 years ago.

Scientists speculated Cygnus X-1 may prove to be what is known as a "black hole," an object that has collapsed to such an extreme density that its gravitational field prevents both energy and ...ping from it.

US satellite finds new X-ray source

By Victor K. McElheny
Globe Staff

The first X-ray observa... in space, designed a... partly built in Cambridg... has discovered a puzzli... new pulsating source ... X-rays in the heavens.

The discovery, announced yesterday ... Baton Rouge, La., ... turn out to be the first ... servation of rays from ... neighborhood or ... thing physicists have ... a "black hole" in the ... verse.

The source, called ... Cygnus X-1 and found ... constellation Cygnus ... like the only ... observed X-ray "p... the Crab Nebul... source puts out ... light pulses like ... pulses, but Cygnu... parently does no... Crab Nebula is ... nant of a huge ... explosion. Cyg... parently is not...

The observations of the Cygnus "pulsar" were ... March 6 by the US ...

... from Cygnus X-1 — is something a little different. It's a place where matter is collecting ... fast and collaps...

An X-Ray Scanning Satellite May Have Discovered a 'Black Hole' in Space

The Darkest Riddle of the Universe

The Darkest Riddle of the Universe

The Dazzling Death Spasm of a Star

The Darkest Riddle of the Universe

The Dazzling Death Spasm of a Star

The Bermuda Triangles of Space

The Darkest Riddle of the Universe

The Dazzling Death Spasm of a Star

The Bermuda Triangles of Space

Vacuum Cleaner of the Cosmos

The Blob That Ate Physics

Black holes may not swallow up the universe, but they could be the graveyard of the laws of physics

BY DIETRICK E. THOMSEN

The term ''naked singularity'' sounds mildly obscene. It is in fact the name of an artifact of the purest mathematical physics, yet if some of the ideas circulating at the Symposium on Theoretical Principles in Astrophysics and Relativity, held at the University of Chicago the last week in May, are correct, it may turn out to be the final cosmic obscenity, the place where 300 years of physics gets the shaft.

''Singularity'' is actually a kind of euphemism. If mathematicians and physicists were allowed to be emotional about their work (in propaganda booklets they are not; in life they often are), they might use stronger language. To a mathematician a singularity is the place where infinities and discontinuities appear in otherwise tractable equations. To a physicist it is the place where the laws of physics go strange. To a general relativist it is the place where space-time becomes unbearably twisted.

A singularity lies at the heart of every black hole. A black hole of the astrophysical sort is one of the things an elderly star can become. Nuclear burning dies out. Its heat no longer supports the body of the star, and the star collapses under its own gravitation until it is so fantastically dense and its gravitational field so strong that neither matter nor radiation nor any kind of signal can escape from it. It is then a black hole, effectively cut off from the universe.

In the world of general relativity, increasing the gravitational field means increasing the curvature of space-time. The deeper into a black hole you go, the sharper the curve. When you reach the center, the twist is so sharp that space-time disappears down the drain, so to speak. Obviously, it's a frightening place for a physicist.

But traditionally physicists didn't have to worry. Every singularity comes clothed in its own black hole. And a black hole is cut off from the universe. It possesses a surface called its event horizon at which gravity is so strong that matter would need an infinite velocity to escape and light is infinitely redshifted and thus effectively extinguished. Communication across the event horizon is not possible. The physicist in the world outside the black hole can get no information from inside it. Since one of the axioms of physics is that if it can't communicate with you, it can't hurt you, physicists needed to lose no sleep over singularities.

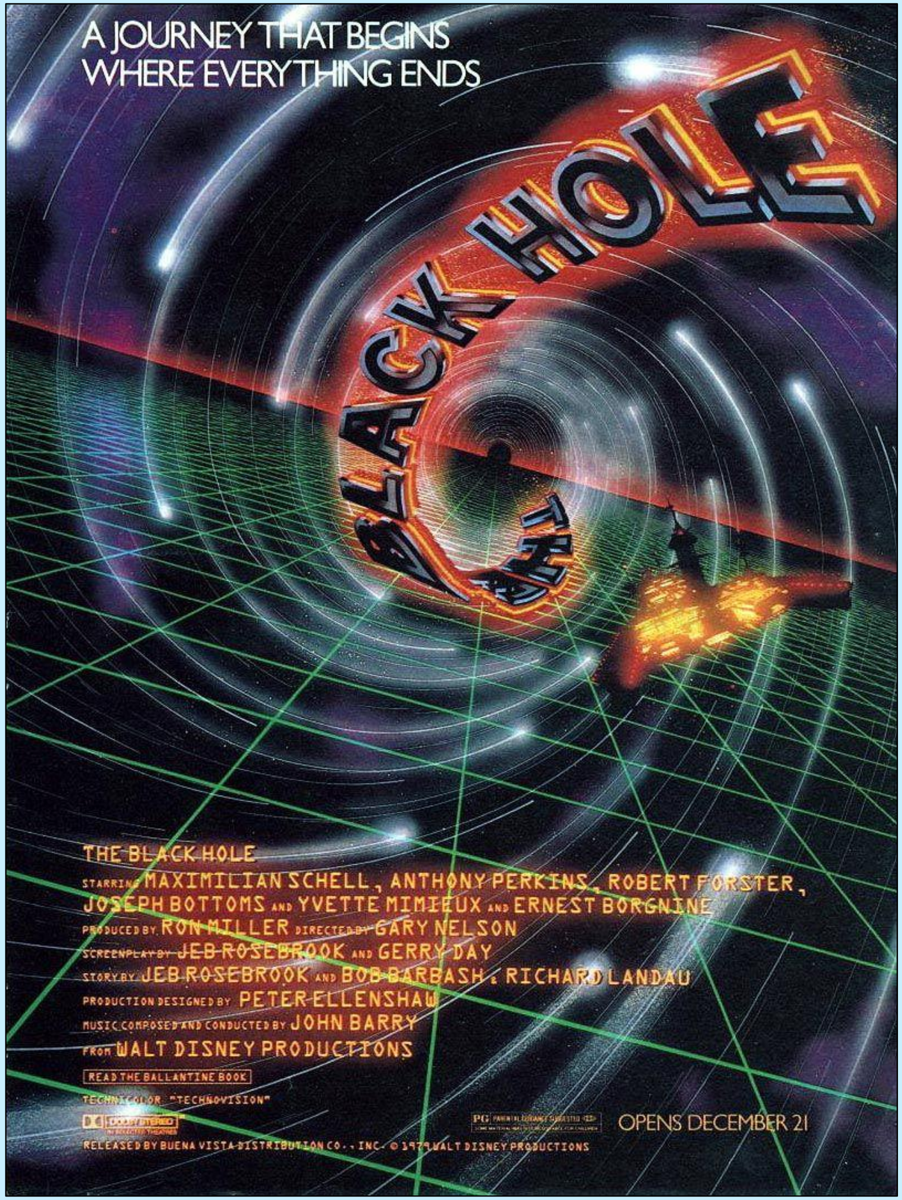
Now comes Stephen W. Hawking of Cambridge University to ring alarm bells in the night. He proposes that certain kinds of communication across the event horizon are possible, that they lead to the explosion or evaporation of the black hole and that the exposure of the singularity leads to the realization that the emperor of physics has no clothes.

Hawking's thought represents an attack on the principle of causality. The principle of causality lies at the basis of physics—no causality, no physics. It says that the state of a physical system at time A determines its state at time B. Knowing the state of the system and the relevant laws of physics, one can predict its future. In classical physics, causality is absolute: Every initial situation has one and only one result. In the world of the atom, quantum mechanics, causality becomes statistical. There are usually several possible states, B, that can result from a given initial state, A, and all the laws give is a way of calculating the probability of one or the other in any instance. Philosophically the change is profoundly disturbing to many physicists, but practically it works because quantum mechanical events come in thousands and millions at a time so all an experimenter wants is a statistical law.

Hawking's thoughts on black holes go farther than previous assaults on the ramparts of causality, destroying quantum mechanical causality along with the classical version. In so doing they knock out another way general relativists had hoped to deal with singularities. General relativity is a classical theory. It lacks a quantized version to deal with subatomic phenomena, but that is being worked on. All right, say the relativists, singularities violate classical physics. A lot of things violate classical physics. When we get a quantized general relativity, we'll know how to deal with singularities. As it happens, Hawking doesn't believe general relativity can be quantized anyhow, but even if it can, it wouldn't be much use in a place where quantum mechanical causality has no meaning.

It all comes about because, as Hawking says: ''Black holes do not last forever.'' The usual assumption was that once a black hole formed, it just sat there. It might occasionally swallow bits of matter

Boston Globe Cartoons
20 January 1974


A JOURNEY THAT BEGINS
WHERE EVERYTHING ENDS
THE BLACK HOLE
THE BLACK HOLE
STARRING MAXIMILIAN SCHELL, ANTHONY PERKINS, ROBERT FORSTER,
JOSEPH BOTTOMS AND YVETTE MIMIEUX AND ERNEST BORGNINE
PRODUCED BY RON MILLER DIRECTED BY GARY NELSON
SCREENPLAY BY JEB ROSEBROOK AND GERRY DAY
STORY BY JEB ROSEBROOK AND BOB BARBASH & RICHARD LANDAU
PRODUCTION DESIGNED BY PETER ELLENSHAW
MUSIC COMPOSED AND CONDUCTED BY JOHN BARRY
FROM WALT DISNEY PRODUCTIONS
READ THE BALLANTINE BOOK
TECHNICOLOR "TECHNOVISION"
PG
OPENS DECEMBER 21
RELEASED BY BUENA VISTA DISTRIBUTION CO., INC. © 1979 WALT DISNEY PRODUCTIONS

New York Times
11 August 1974

Letters

What next?

To the Editor:

I am an average 32-year-old houseperson, but a cloud hangs over my life, and I am afraid.

For the last 15 years of my Sundays, The Times Magazine has been alerting and preparing me; gradually, the parade of inevitable disasters goes marching by. Late in the fifties, it began: first the bomb, then cigarette smoking, the pill, auto exhaust fumes, all the pollution-environment fears, dying oceans, no trees, etc., and, of course, overpopulation. And now in the seventies, new fears added to the old: stolen A-bombs, asbestos, and the latest terror of terrors — the black hole ("A hole in the sky," July 14). Maybe scientists can't see it, but I have, every day since Walter Sullivan's article appeared. My whole world gradually being sucked in, like cracker crumbs into the Electrolux: the earth, the moon, all my friends, my Martex towels, my old yearbooks, my work, maybe even The New York Times—whirling to the ultimate destruction, anti-ing themselves.

Please, next Sunday, some good news, some hope. *Please.*

BETSY KIMBALL DEMPSEY
Haworth, N. J.

New York Times
11 August 1974

Letters

What next?

To the Editor:

I am an average 32-year-old houseperson, but a cloud hangs over my life, and I am afraid.

For the last 15 years of my Sundays, The Times Magazine has been alerting and preparing me; gradually, the parade of inevitable disasters goes marching by. Late in the fifties, it began: first the bomb, then cigarette smoking, the pill, auto exhaust fumes, all the pollution-environment fears, dying oceans, no trees, etc., and, of course, overpopulation. And now in the seventies, new fears added to the old: stolen A-bombs, asbestos, and the latest terror of terrors — the black hole ("A hole in the sky," July 14). Maybe scientists can't see it, but I have, every day since Walter Sullivan's article appeared. My whole world gradually being sucked in, like cracker crumbs into the Electrolux: the earth, the moon, all my friends, my Martex towels, my old yearbooks, my work, maybe even The New York Times—whirling to the ultimate destruction, anti-ing themselves.

Please, next Sunday, some good news, some hope. *Please.*

BETSY KIMBALL DEMPSEY
Haworth, N. J.

New York Times
11 August 1974

Letters

What next?

To the Editor:

I am an average 32-year-old houseperson, but a cloud hangs over my life, and I am afraid.

For the last 15 years of my Sundays, The Times Magazine has been alerting and preparing me; gradually, the parade of inevitable disasters goes marching by. Late in the fifties, it began: first the bomb, then cigarette smoking, the pill, auto exhaust fumes, all the pollution-environment fears, dying oceans, no trees, etc., and, of course, overpopulation. And now in the seventies, new fears added to the old: stolen A-bombs, asbestos, and the latest terror of terrors — the black hole ("A hole in the sky," July 14). Maybe scientists can't see it, but I have, every day since Walter Sullivan's article appeared. My whole world gradually being sucked in, like cracker crumbs into the Electrolux: the earth, the moon, all my friends, my Martex towels, my old yearbooks, my work, maybe even The New York Times—whirling to the ultimate destruction, anti-ing themselves.

Please, next Sunday, some good news, some hope. *Please.*

BETSY KIMBALL DEMPSEY
Haworth, N. J.

A Suggestion

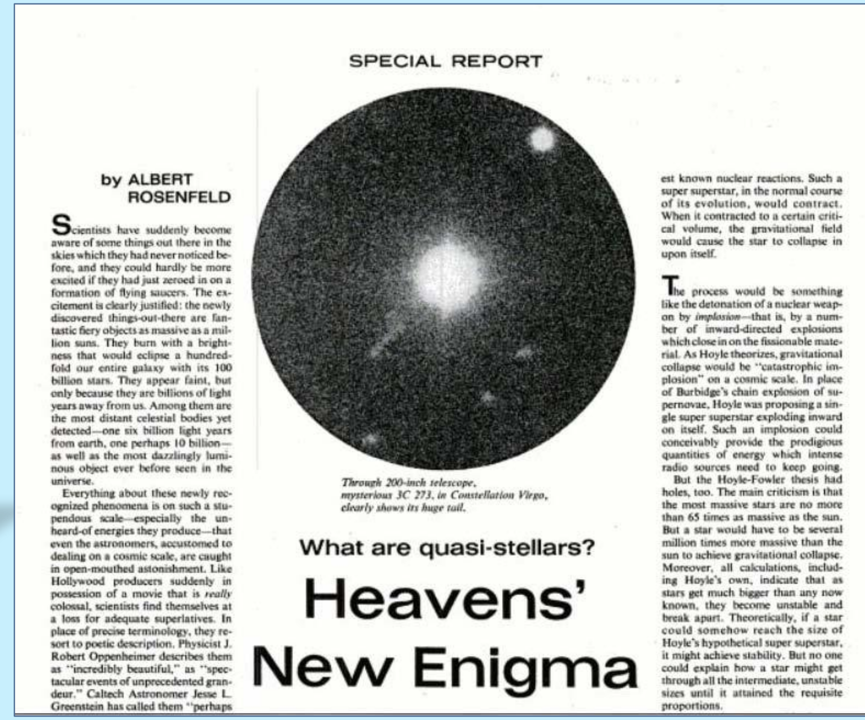
24 July 1972

Editor, The Wall Street Journal:

Having read the Journal's recent lead article on black holes, I earnestly suggest that future reporting be restricted to financial matters.

EDWIN T. ALSAKER
Atlanta


I HAVE
BLACK HOLE



SPECIAL REPORT

by ALBERT ROSENFELD

Scientists have suddenly become aware of some things out there in the skies which they had never noticed before, and they could hardly be more excited if they had just zeroed in on a formation of flying saucers. The excitement is clearly justified: the newly discovered things-out-there are fantastic fiery objects as massive as a million suns. They burn with a brightness that would eclipse a hundredfold our entire galaxy with its 100 billion stars. They appear faint, but only because they are billions of light years away from us. Among them are the most distant celestial bodies yet detected—one six billion light years from earth, one perhaps 10 billion—as well as the most dazzlingly luminous object ever before seen in the universe.

Everything about these newly recognized phenomena is on such a stupendous scale—especially the unheard-of energies they produce—that even the astronomers, accustomed to dealing on a cosmic scale, are caught in open-mouthed astonishment. Like Hollywood producers suddenly in possession of a movie that is *really* colossal, scientists find themselves at a loss for adequate superlatives. In place of precise terminology, they resort to poetic description. Physicist J. Robert Oppenheimer describes them as "incredibly beautiful," as "spectacular events of unprecedented grandeur." Caltech Astronomer Jesse L. Greenstein has called them "perhaps

Through 200-inch telescope, mysterious 3C 273, in Constellation Virgo, clearly shows its huge tail.

What are quasi-stellars?

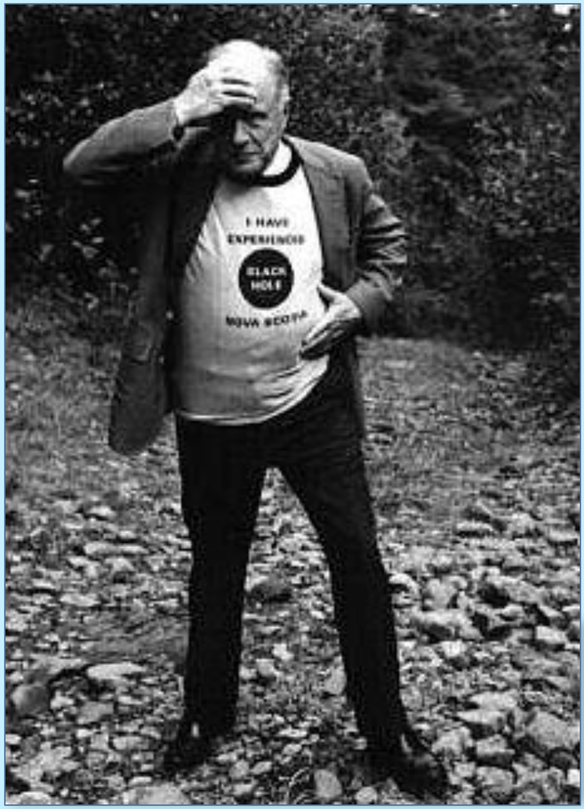
Heavens' New Enigma

est known nuclear reactions. Such a super superstar, in the normal course of its evolution, would contract. When it contracted to a certain critical volume, the gravitational field would cause the star to collapse in upon itself.

The process would be something like the detonation of a nuclear weapon by *implosion*—that is, by a number of inward-directed explosions which close in on the fissionable material. As Hoyle theorizes, gravitational collapse would be "catastrophic implosion" on a cosmic scale. In place of Burbidge's chain explosion of supernovae, Hoyle was proposing a single super superstar exploding inward on itself. Such an implosion could conceivably provide the prodigious quantities of energy which intense radio sources need to keep going.

But the Hoyle-Fowler thesis had holes, too. The main criticism is that the most massive stars are no more than 65 times as massive as the sun. But a star would have to be several million times more massive than the sun to achieve gravitational collapse. Moreover, all calculations, including Hoyle's own, indicate that as stars get much bigger than any now known, they become unstable and break apart. Theoretically, if a star could somehow reach the size of Hoyle's hypothetical super superstar, it might achieve stability. But no one could explain how a star might get through all the intermediate, unstable sizes until it attained the requisite proportions.

Life Magazine — 24 Jan 1964

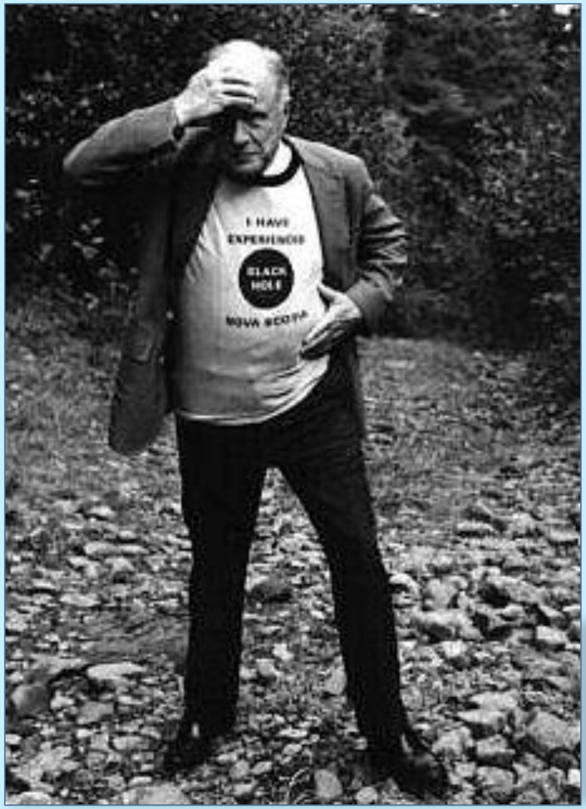


nova could not do the trick. But what about a chain of explosions? An A-bomb explosion is caused by a chain reaction of fissioning atoms when the uranium reaches a certain critical mass. Burbidge theorized that a chain reaction of supernovae might also occur—each one setting off the others around it in turn—when a galaxy reached a certain critical stage in its evolution.

The trouble with this idea was that it called for a highly improbable kind of galaxy with a core of stars ready to explode into supernovae and so densely packed that they could be detonated at the rate of 10 to 1,000 per year. (In our own galaxy a supernova occurs less than once in a century.)

Among those reluctant to accept Burbidge's idea was the celebrated cosmologist, Fred Hoyle of Cambridge University. In collaboration with Physicist William A. Fowler of Caltech, he proposed an even more daring theory: gravitational collapse. The greater an object's mass, the greater its gravitational force. If a star could attain a certain mass—say a million to 100 million times the

Another important objection to Hoyle's idea was built into Einstein's general theory of relativity. Gravity, as every earthling knows, is what keeps us all from floating off into space. To escape gravity a certain speed is required—the so-called "escape velocity." To escape earth gravity, the 25,000 mph achieved by large rockets is enough. To escape from a larger planet like Jupiter, with a stronger gravitational field, would require a greater escape velocity. Now Einstein's theory predicts that if the gravitational collapse of a star did occur, the collapse would go on and the gravitational field would become stronger and stronger until it grew so powerful that it would close in upon itself; ultimately, the escape velocity would equal the speed of light, which is the speed limit of the universe. In that case nothing could get out of the star, not even light waves. Thus, instead of an intensely radiating object, sending out lavish quantities of light and radio energy, gravitational collapse would result in an invisible "black hole" in the universe. (To attain this "black hole" status, the matter comprising the earth would have to be compressed to a



nova could not do the trick. But what about a chain of explosions? An A-bomb explosion is caused by a chain reaction of fissioning atoms when the uranium reaches a certain critical mass. Burbidge theorized that a chain reaction of supernovae might also occur—each one setting off the others around it in turn—when a galaxy reached a certain critical stage in its evolution.

The trouble with this idea was that it called for a highly improbable kind of galaxy with a core of stars ready to explode into supernovae and so densely packed that they could be detonated at the rate of 10 to 1,000 per year. (In our own galaxy a supernova occurs less than once in a century.)

Among those reluctant to accept Burbidge's idea was the celebrated cosmologist, Fred Hoyle of Cambridge University. In collaboration with Physicist William A. Fowler of Caltech, he proposed an even more daring theory: gravitational collapse. The greater an object's mass, the greater its gravitational force. If a star could attain a certain mass—say a million to 100 million times the

Another important objection to Hoyle's idea was built into Einstein's general theory of relativity. Gravity, as every earthling knows, is what keeps us all from floating off into space. To escape gravity a certain speed is required—the so-called "escape velocity." To escape earth gravity, the 25,000 mph achieved by large rockets is enough. To escape from a larger planet like Jupiter, with a stronger gravitational field, would require a greater escape velocity. Now Einstein's theory predicts that if the gravitational collapse of a star did occur, the collapse would go on and the gravitational field would become stronger and stronger until it grew so powerful that it would close in upon itself; ultimately, the escape velocity would equal the speed of light, which is the speed limit of the universe. In that case nothing could get out of the star, not even light waves. Thus, instead of an intensely radiating object, sending out lavish quantities of light and radio energy, gravitational collapse would result in an invisible "black hole" in the universe. (To attain this "black hole" status, the matter comprising the earth would have to be compressed to a

ASTRONOMY

"Black Holes" in Space

The heavy densely packed dying stars that speckle space may help determine how matter behaves when enclosed in its own gravitational field—By Ann Ewing

➤ SPACE may be peppered with "black holes."

This was suggested at the American Association for the Advancement of Science meeting in Cleveland by astronomers and physicists who are experts on what are called degenerate stars.

Degenerate stars are not Hollywood types with low morals. They are dying stars, or white dwarfs, and make up about 10% of all stars in the sky.

The faint light they emit comes from the little heat left in their last stages of life. It is not known how a star quietly declines to become a white dwarf.

Degenerate stars are made of densely packed electrons and nuclei, or cores of atoms. They are so dense that a thimbleful of their matter weighs a ton.

Some such stars are predicted in theory to have a density of one million tons per thimbleful. When this happens, the star is essentially made of neutrons and strange particles.

Because a degenerate star is so dense, its gravitational field is very strong. According to Einstein's general theory of relativity, as mass is added to a degenerate star a sudden collapse will take place and the intense gravitational field of the star will close in on itself.

Such a star then forms a "black hole" in the universe.

Modern tools, such as telescopes on an orbiting space platform, may be used to detect such black holes and to help determine how matter behaves when it is enclosed by its own gravitational field.

The light from the most famous white dwarf star, Sirius B, a companion to Sirius—which is the brightest star in the heavens visible from earth—has been captured using the 200-inch telescope atop Mt. Palomar. This was done as part of a program to study at least 20 white dwarfs.

Preliminary analysis of the light from Sirius B indicates that it has an effective temperature of 16,800 degrees Kelvin, or 30,000 degrees Fahrenheit. Its radius can be calculated from the temperature, and is only nine-thousandths that of the sun.

The star must therefore consist mainly of helium or heavier elements.

The speakers at the symposium were Drs. A. G. W. Cameron of the National Aeronautics and Space Administration's Goddard Institute for Space Studies, New York; Charles Misner of the University of Maryland; Volker Weidemann, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, and J. B. Oke of California Institute of Technology. The symposium was arranged by Dr. Hong-yee Chiu of the Goddard Institute for Space Studies.

• Science News Letter, 85:39 Jan. 18, 1964

METEOROLOGY

Weather Vans Promise Better Local Forecasts

➤ ON-THE-SPOT weather data from satellites soon will be available directly to local forecasters through the use of special vans being outfitted by the Government.

The vans receive signals through a spiral-shaped roof-top antenna and provide cloud cover pictures of the local area as "seen" by the weather satellite.

Pictures will be used by weather forecasters in the van for vast, large-scale cloud observations not now possible.

The vans, which can be transported by air or truck, are being tested at Hanscom Field, Mass., by the Air Force, the U.S. Weather Bureau and the National Aeronautics and Space Administration.

Inside weather satellites, such as Tiros and Nimbus, television transmission devices automatically take and transmit a cloud picture every three minutes during daylight. Each picture received by the vans will cover an area of about 640,000 square miles, from which the operator will be able to make his weather analysis.

In an emergency the mobile stations can be flown to any spot in the world and placed in operation in as little as two hours after landing. They can be used in military operations and for locating and tracking severe storms such as hurricanes and typhoons.

• Science News Letter, 85:39 Jan. 18, 1964

SPACE

Spot Positrons From Space

➤ A BALLOON carrying its own magnetic field has been used positively to spot positrons from space for the first time, three scientists reported in New York.

Positrons are anti-particles of electrons, and have been created artificially and detected in unstable elements.

Although positrons have been known for years to be a part of the cosmic radiation continually bombarding earth from space, they have not been directly detected in cosmic rays before because there was no way to sort them out from electrons.

However, scientists from the University of Chicago and Argonne National Laboratory solved this problem by sending aloft, at a point where the earth's magnetic field is weakest, a balloon with an atomic particle detector having its own magnetic field.

Photographs of the atomic debris in the particle detector showed whether the electrons were negatively or positively charged by how they curved in the magnetic field. The ratio of three to one between the numbers of electrons and positrons indicates how these particles are born in space.

The high-altitude experiment, conducted from Fort Churchill, Canada, was reported in Physical Review Letters, 12:3, 1964, by Drs. Peter Meyer and Roger H. Hildebrand of the University of Chicago and Dr. James A. DeShong of Argonne National Laboratory.

They believe there are two independent processes at work to form cosmic ray electrons:

1. The explosion of stars, or supernovas, during which electrons are shot into space.

2. The collision of protons with other protons in space, as can be made to happen on earth in giant atom smashers. From such particle collisions are formed neutral pi mesons that finally decay into equal numbers of electrons and positrons.

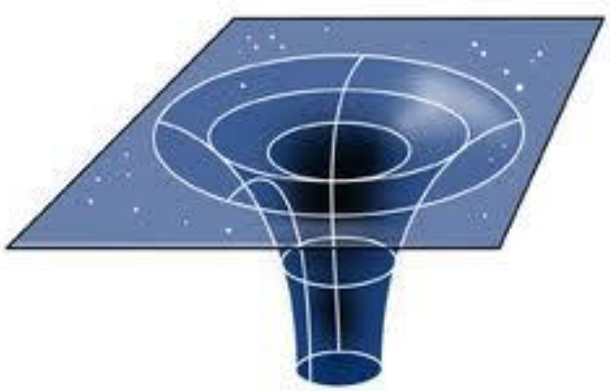
Funds for the experiment were provided by the National Aeronautics and Space Administration and the Atomic Energy Commission.

The Office of Naval Research and the Royal Canadian Air Force provided support facilities.

• Science News Letter, 85:39 Jan. 18, 1964

U.S. Navy

GLASS SUBMARINES?—Hollow spheres of common glass, because of their high compressive strength and relatively low weight, may be used for hulls of deep-diving submarines of the future. Robert M. Charles, engineer at the U.S. Navy's David Taylor Model Basin, Washington, D. C., is shown placing a hollow glass sphere into a pressure tank for hydrostatic testing.



Bermuda Triangles of Space

How the Public First Met Black Holes

Marcia Bartusiak – MIT