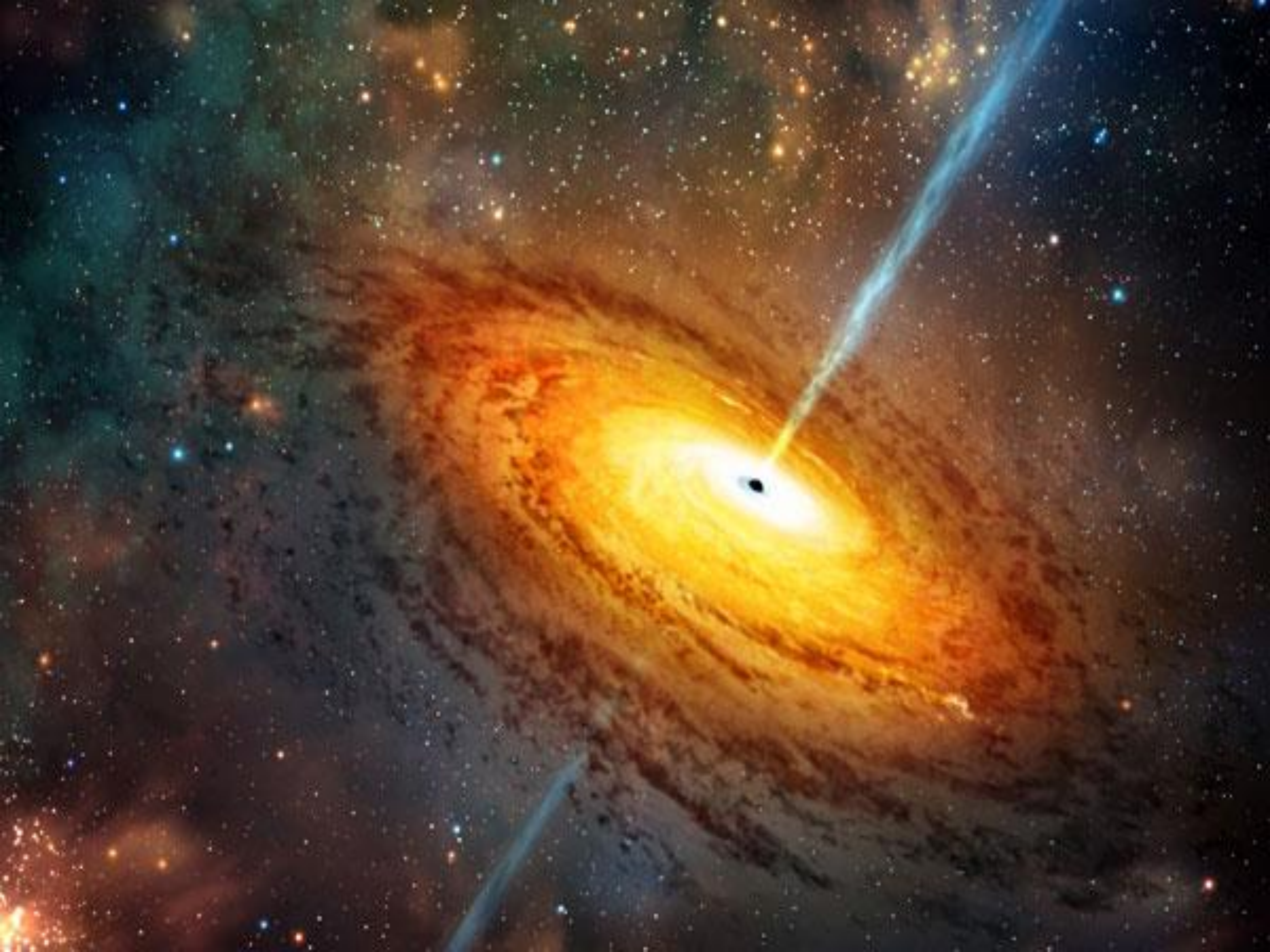
Black Hole

How an Idea Abandoned by Newtonians
Hated by Einstein
And Gambled on by Hawking
Became Loved

by Marcia Bartusiak

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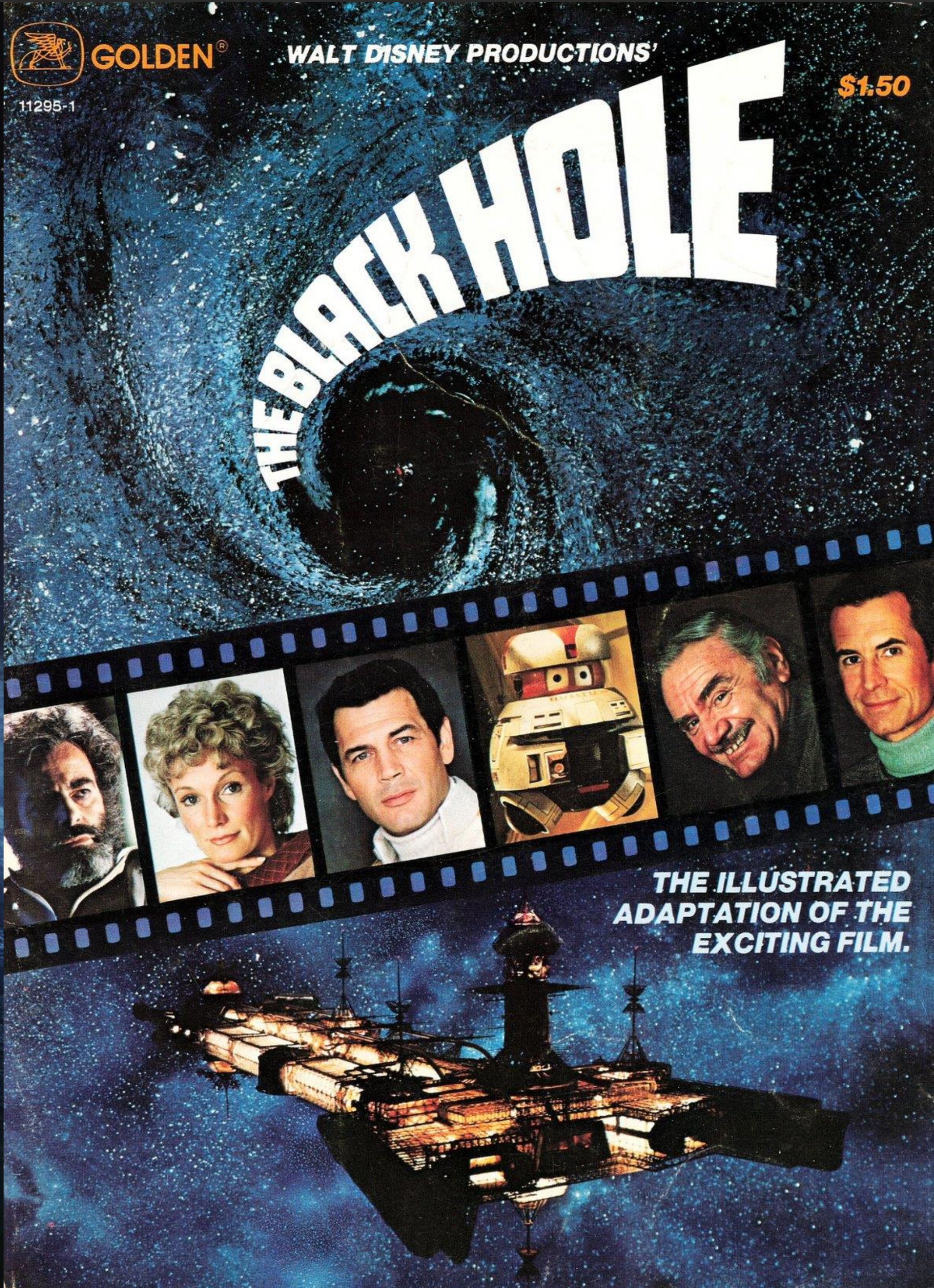
GOLDEN®
11295-1
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THE BLACK HOLE
THE ILLUSTRATED ADAPTATION OF THE EXCITING FILM.


REVD
JOHN MICHELL BD. FRS
1724 - 1793
GEOLOGIST AND ASTRONOMER
RECTOR OF THORNHILL 1767 - 1793
HE EXPERIMENTED ON MAGNETISM AND
ASTRONOMY, ALSO MAKING A TORSION BALANCE
TO WEIGH THE WORLD. HIS VISITORS HERE
INCLUDED HENRY CAVENDISH,
WILLIAM HERSCHEL, JOSEPH PRIESTLEY
AND JOHN SMEATON.

VII. *On the Means of discovering the Distance, Magnitude, &c. of the Fixed Stars, in consequence of the Diminution of the Velocity of their Light, in case such a Diminution should be found to take place in any of them, and such other Data should be procured from Observations, as would be farther necessary for that Purpose. By the Rev.* John Michell, *B. D. F. R. S. In a Letter to* Henry Cavendish, *Esq. F. R. S. and A. S.*

Read November 27, 1783.

DEAR SIR, Thornhill, May 26, 1783.

THE method, which I mentioned to you when I was last in London, by which it might perhaps be possible to find the distance, magnitude, and weight of some of the fixed stars, by means of the diminution of the velocity of their light, occurred to me soon after I wrote what is mentioned by Dr. Priestley in his History of Optics, concerning the diminution of the velocity of light in consequence of the attraction of the sun; but the extreme difficulty, and perhaps impossibility, of procuring the other data necessary for this purpose appeared to me to be such objections against the scheme, when I first thought of it, that I gave it then no farther consideration. As some late observations, however, begin to give us a little more chance of procuring some at least of these data, I thought it would not be amiss, that astronomers should be apprized of the method, I propose (which, as far as I know,

has

16. Hence, according to article 10, if the femi-diameter of a fphære of the fame denfity with the fun were to exceed that of the fun in the proportion of 500 to 1, a body falling from an infinite height towards it, would have acquired at its furface a greater velocity than that of light, and confequently, fuppofing light to be attracted by the fame force in proportion to its vis inertiæ, with other bodies, all light emitted from fuch a body would be made to return towards it, by its own proper gravity.

17. But if the femi-diameter of a fphære, of the fame denfity with the fun, was of any other fize lefs than 497 times that of the fun, though the velocity of the light emitted from fuch a body, would never be wholly deftroyed, yet would it always fuffer fome diminution, more or lefs, according to the magnitude of the faid fphære; and the quantity of this diminution may be eafily found in the following manner: Suppofe S to reprefent the femi-diameter of the fun, and aS to reprefent the femi-diameter of the propofed fphære; then, as appears from what has been fhewn before, the fquare root of the difference between the fquare of 497 S and the fquare of aS will be always proportional to the ultimately remaining velocity, after it has fuffered all the diminution, it can poffibly fuffer from this caufe; and confequently the difference between the whole velocity of light, and the remaining velocity, as found above, will be the diminution of its velocity. And hence the diminution of the velocity of light emitted from the fun, on account of it's gravitation towards that body, will be fomewhat lefs than a 494.000dth part of the velocity which it would have had if no fuch diminution had taken place; for the fquare of 497 being 247.009, and the fquare of 1 being 1, the diminution of the velocity will be the difference between

16. Hence, according to article 10, if the semi-diameter of a sphære of the same density with the sun were to exceed that of the sun in the proportion of 500 to 1, a body falling from an infinite height towards it, would have acquired at its surface a greater velocity than that of light, and consequently, supposing light to be attracted by the same force in proportion to its vis inertiæ, with other bodies, all light emitted from such a body would be made to return towards it, by its own proper gravity.

17. But if the semi-diameter of a sphære, of the same density with the sun, was of any other size less than 497 times that of the sun, though the velocity of the light emitted from such a body, would never be wholly destroyed, yet would it always suffer some diminution, more or less, according to the magnitude of the said sphære; and the quantity of this diminution may be easily found in the following manner: Suppose S to represent the semi-diameter of the sun, and aS to represent the semi-diameter of the proposed sphære; then, as appears from what has been shewn before, the square root of the difference between the square of 497 S and the square of aS will be always proportional to the ultimately remaining velocity, after it has suffered all the diminution, it can possibly suffer from this cause; and consequently the difference between the whole velocity of light, and the remaining velocity, as found above, will be the diminution of its velocity. And hence the diminution of the velocity of light emitted from the sun, on account of it's gravitation towards that body, will be somewhat less than a 494.000dth part of the velocity which it would have had if no such diminution had taken place; for the square of 497 being 247.009, and the square of 1 being 1, the diminution of the velocity will be the difference between

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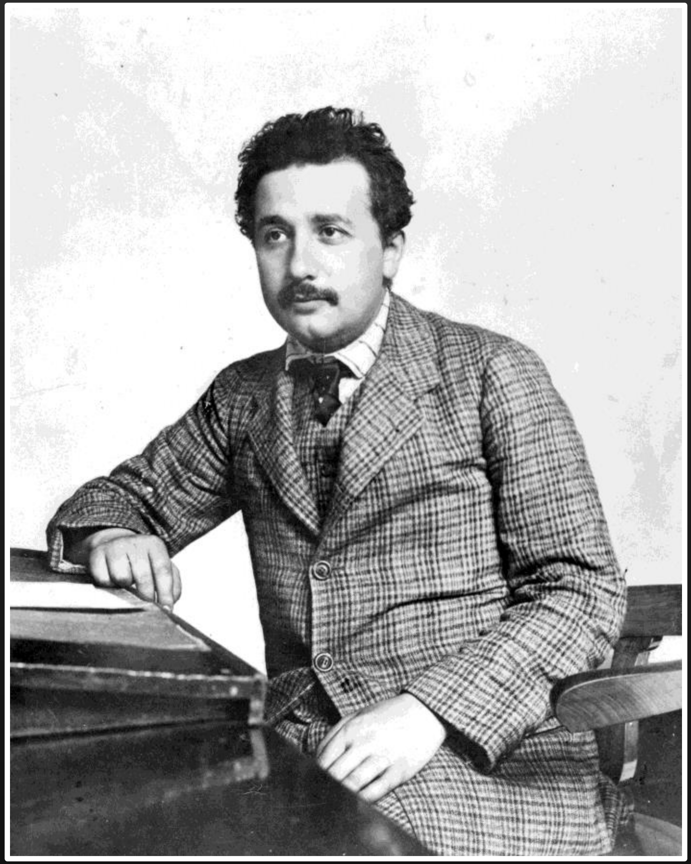

Albert Einstein

Albert Einstein

General Relativity

$$R_{uv} - \frac{1}{2} g_{uv} R = T_{uv}$$

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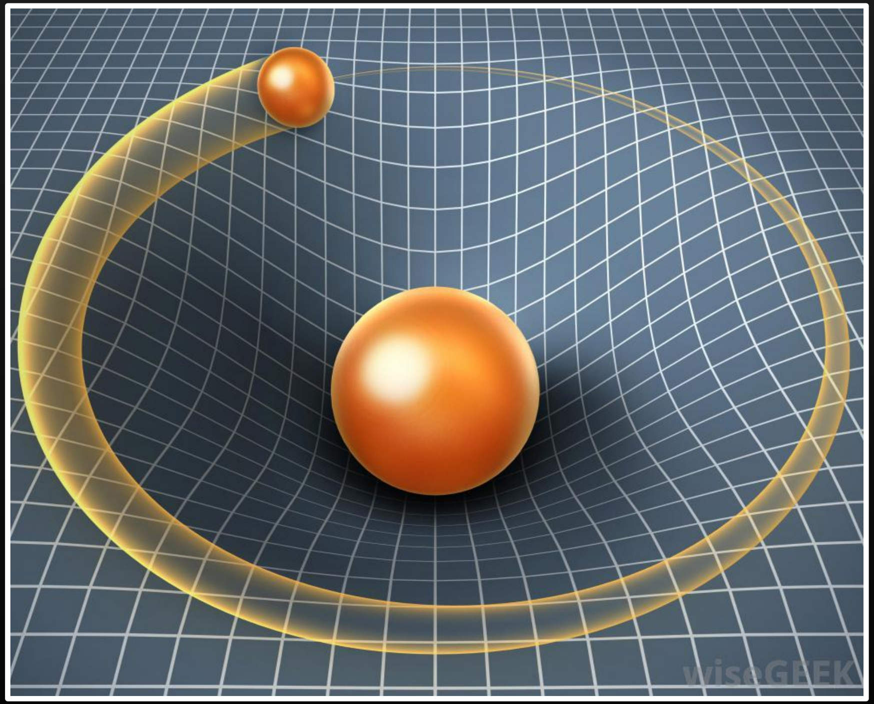
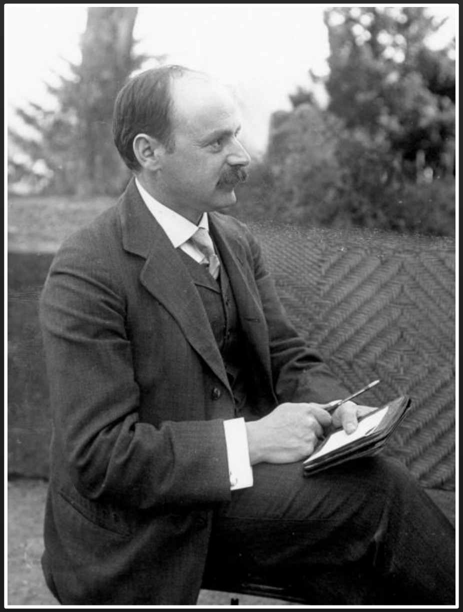
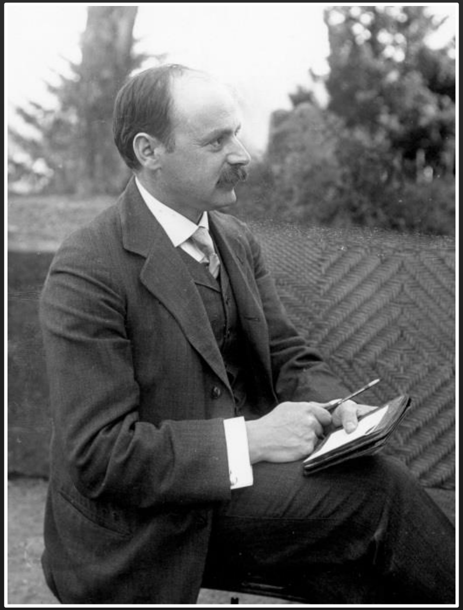




Karl Schwarzschild



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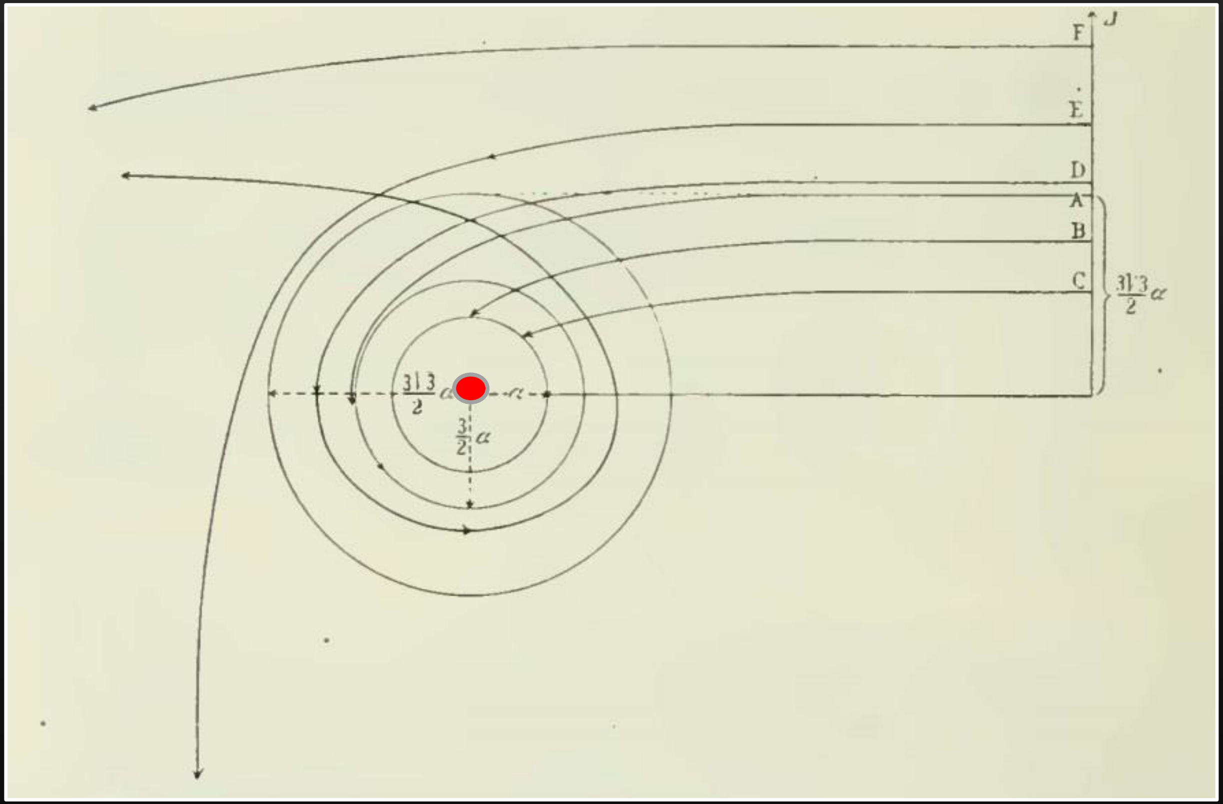

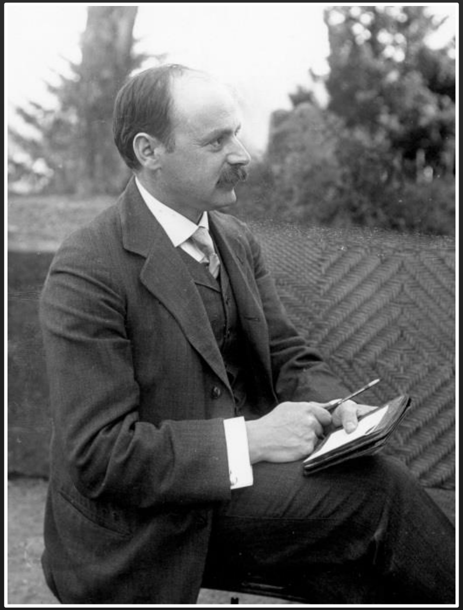

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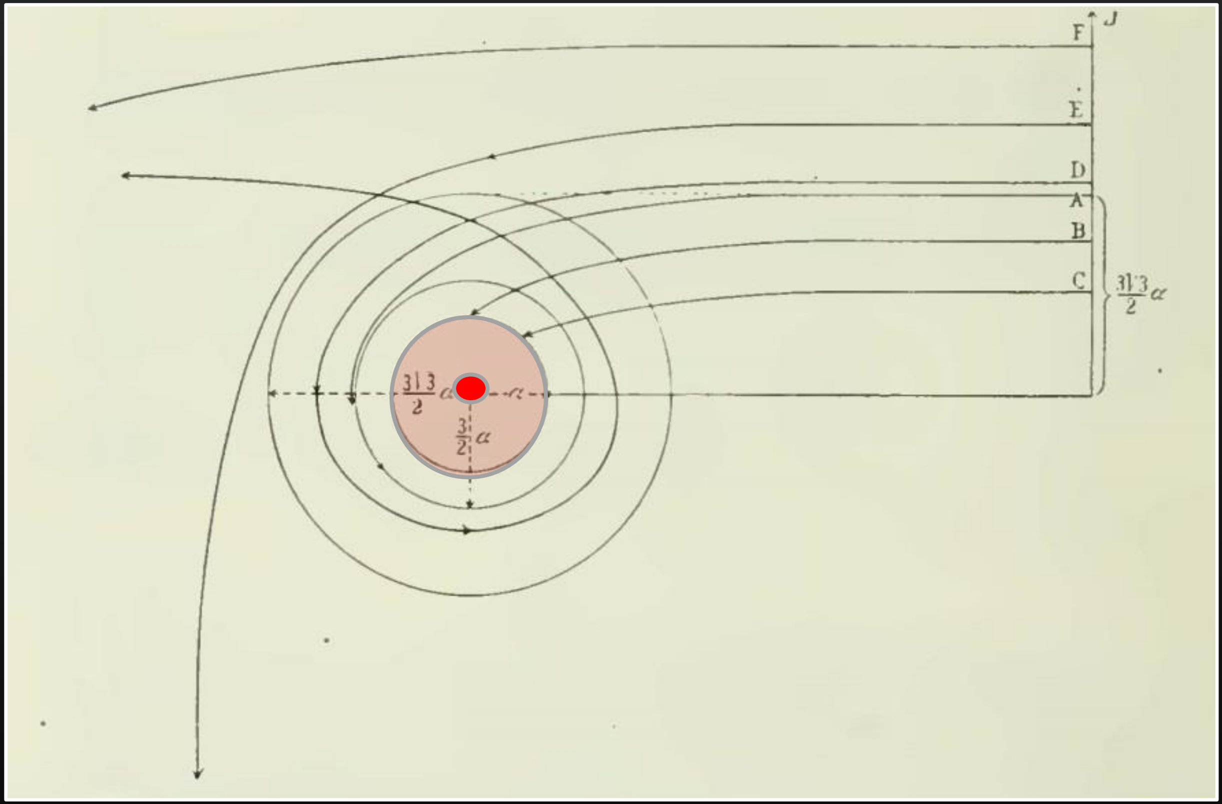

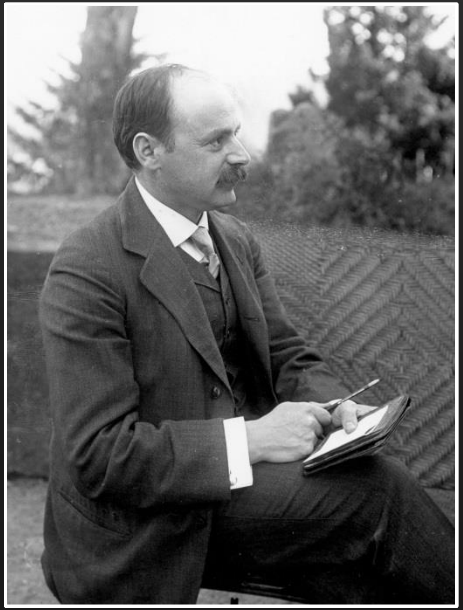

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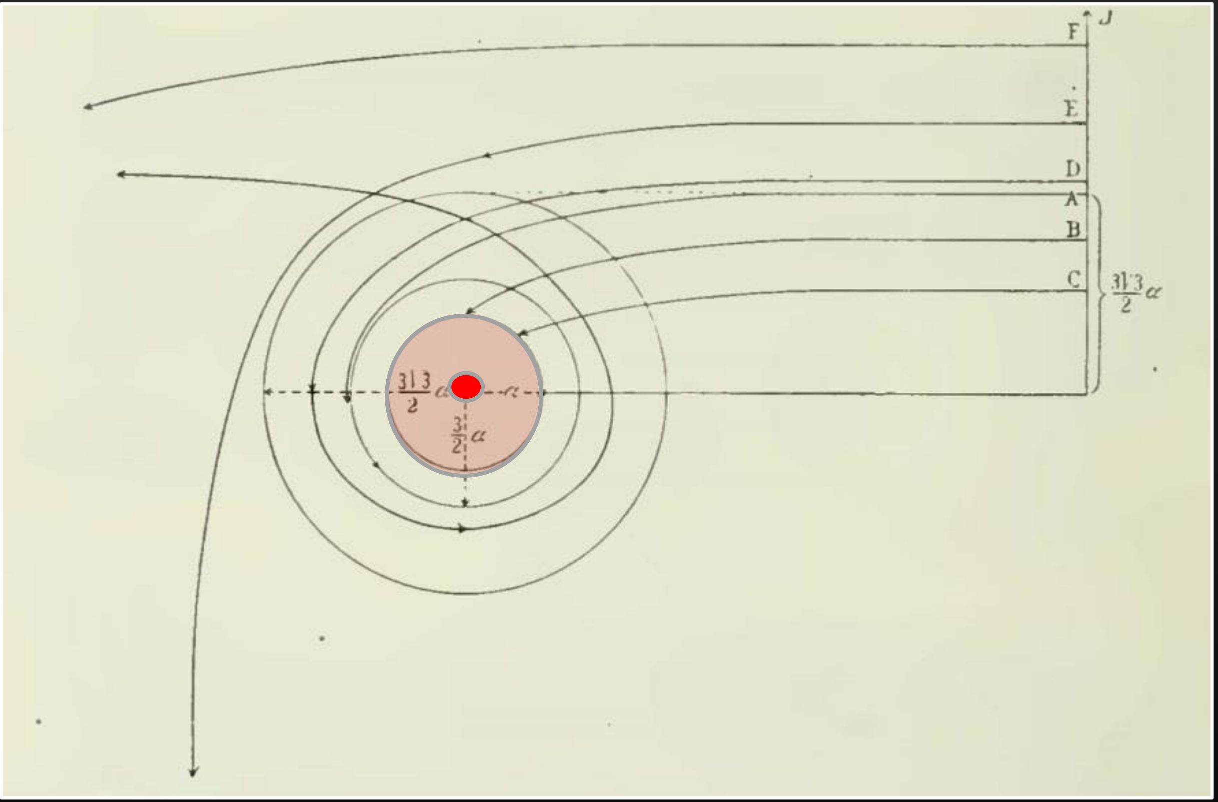
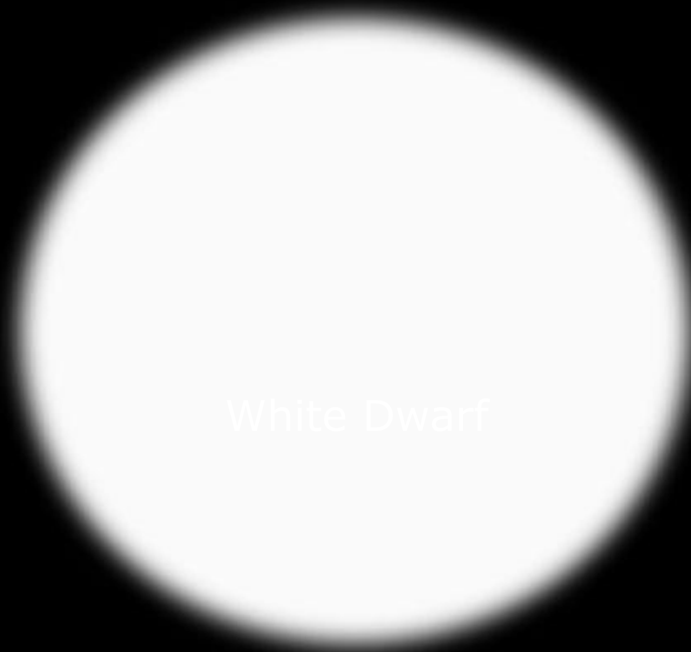


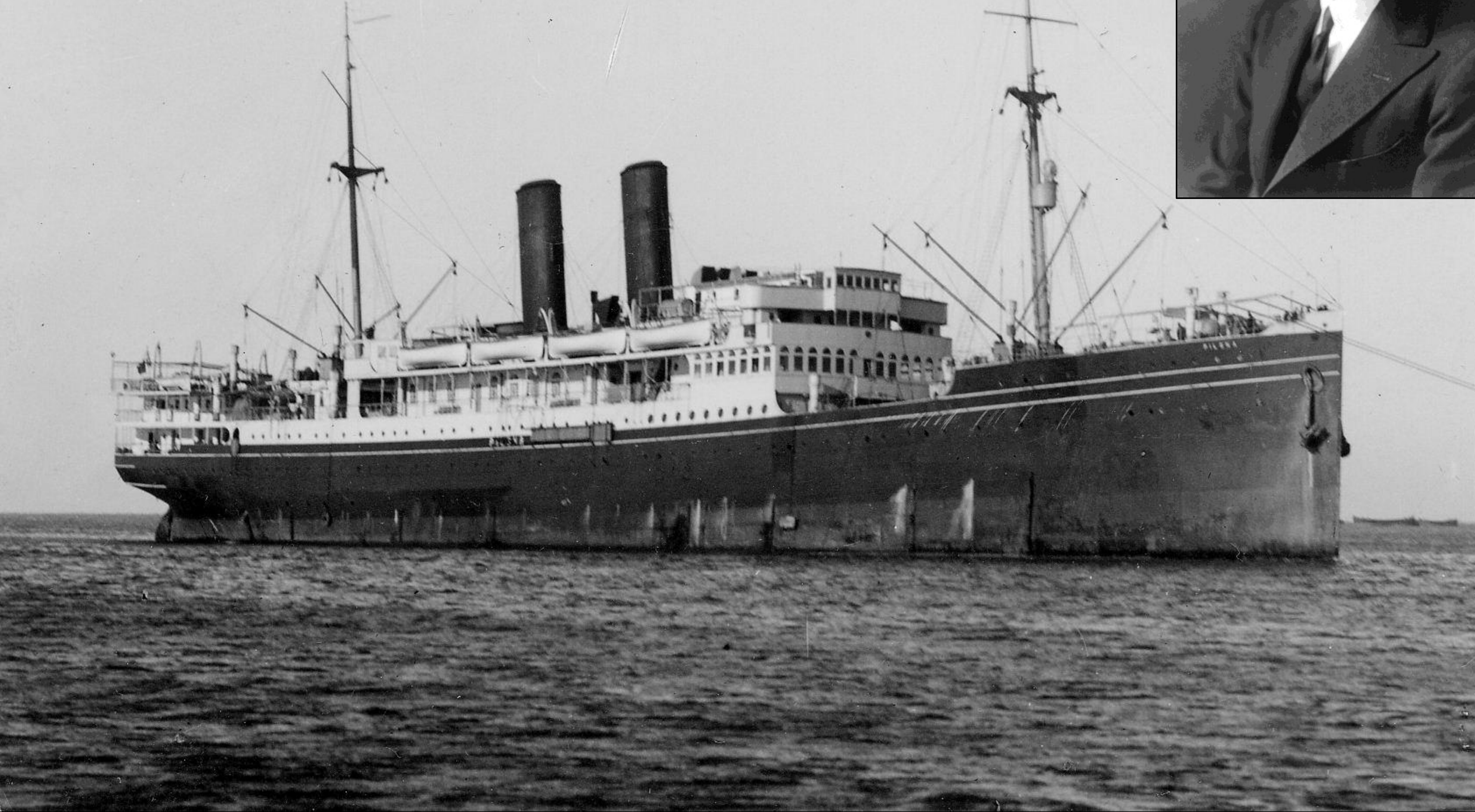
"Clearly not physically meaningful"

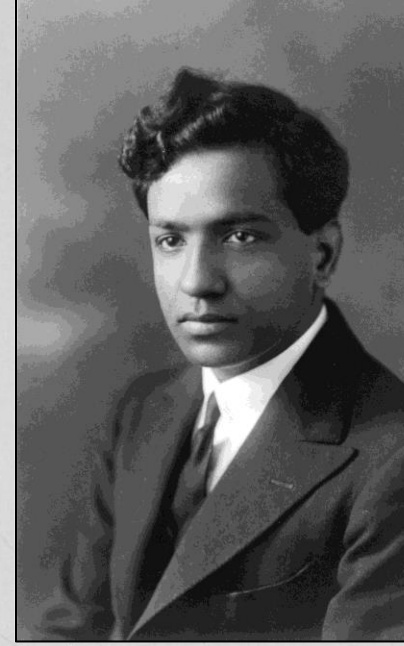
White Dwarf



White Dwarf

Subrahmanyan Chandrasekhar
1930





Subrahmanyan Chandrasekhar
1930

Chandra's Findings

A Limit to White Dwarf Mass!   1.4 solar masses

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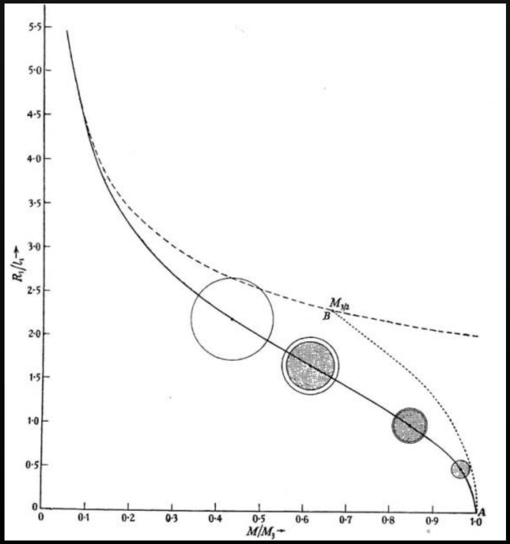

Royal Astronomical Society

London, 11 January 1935

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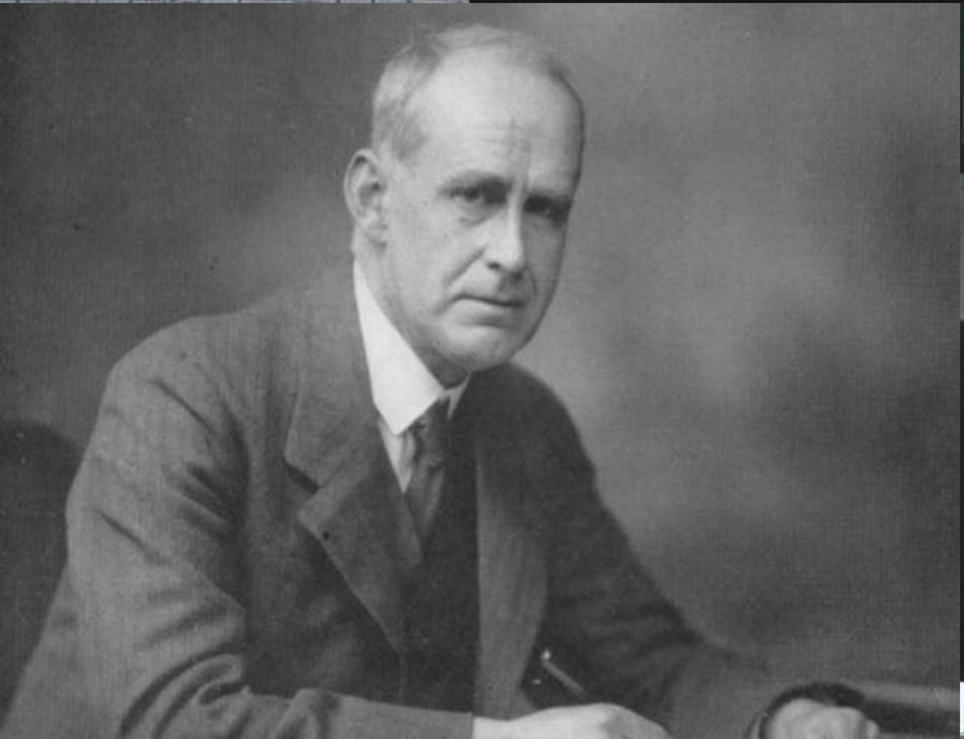

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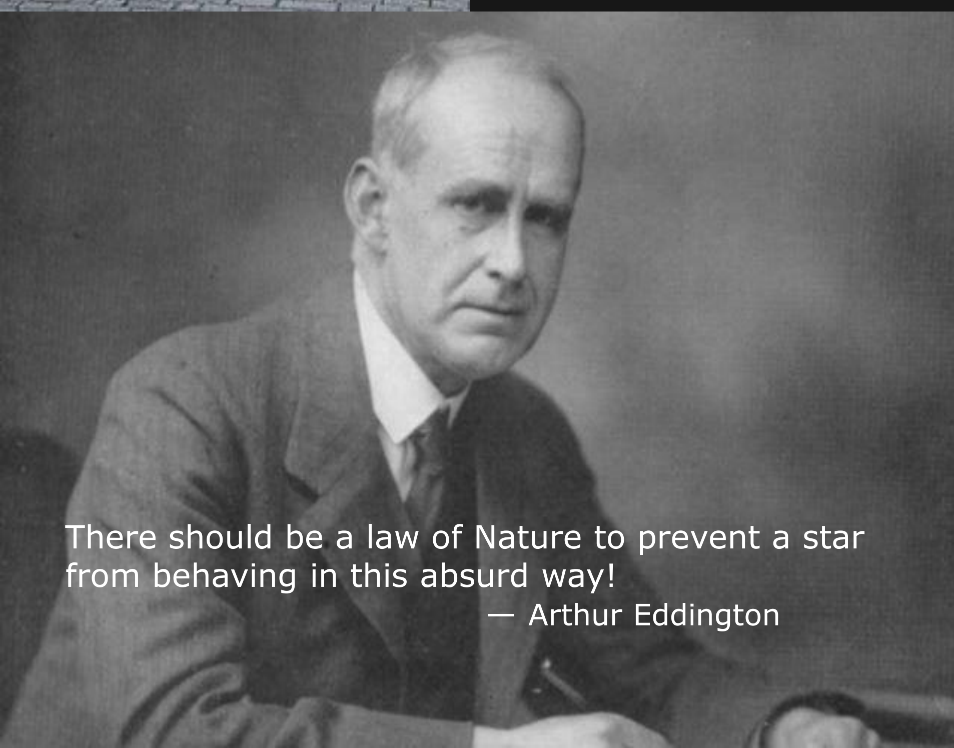


There should be a law of Nature to prevent a star from behaving in this absurd way!
— Arthur Eddington

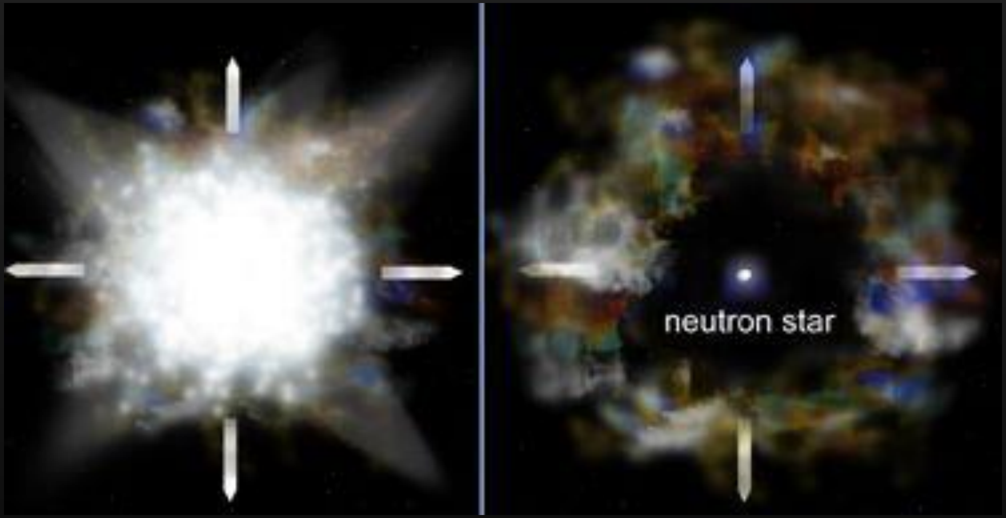
Fritz Zwicky

Walter Baade

Fritz Zwicky

Walter Baade

Supernova!



1933

J. Robert Oppenheimer

J. Robert Oppenheimer

George Volkoff

15 February 1939

FEBRUARY 15, 1939 PHYSICAL REVIEW VOLUME 55

On Massive Neutron Cores

J. R. Oppenheimer and G. M. Volkoff
Department of Physics, University of California, Berkeley, California

(Received January 3, 1939)

It has been suggested that, when the pressure within stellar matter becomes high enough, a new phase consisting of neutrons will be formed. In this paper we study the gravitational equilibrium of masses of neutrons, using the equation of state for a cold Fermi gas, and general relativity. For masses under $\frac{1}{3}\odot$ only one equilibrium solution exists, which is approximately described by the nonrelativistic Fermi equation of state and Newtonian gravitational theory. For masses $\frac{1}{3}\odot < m < \frac{3}{4}\odot$ two solutions exist, one stable and quasi-Newtonian, one more condensed, and unstable. For masses greater than $\frac{3}{4}\odot$ there are no static equilibrium solutions. These results are qualitatively confirmed by comparison with suitably chosen special cases of the analytic solutions recently discovered by Tolman. A discussion of the probable effect of deviations from the Fermi equation of state suggests that actual stellar matter after the exhaustion of thermonuclear sources of energy will, if massive enough, contract indefinitely, although more and more slowly, never reaching true equilibrium.

I. Introduction

For the application of the methods commonly used in attacking the problem of stellar structure[1] the distribution of energy sources and their dependence on the physical conditions within the star must be known. Since at the time of Eddington's original studies not much was known about the physical processes responsible for the generation of energy within a star, various mathematically convenient assumptions were made in regard to the energy sources, and these led to different star models (e.g. the Eddington model, the point source model, etc.). It was found that with a given equation of state for the stellar material many important properties of the solutions (such as the mass-luminosity law) were quite insensitive to the choice of assumptions about the distribution of energy sources, but were common to a wide range of models.

In 1932 Landau[2] proposed that instead of making arbitrary assumptions about energy sources chosen merely for mathematical convenience, one should attack the problem by first investigating the physical nature of the equilibrium of a given mass of material in which no energy is generated, and from which there is no radiation, presumably in the hope that such an investigation would afford some insight into the more general situation where the generation of energy is taken into account. Although such a model gives a good description of a white dwarf star in which most of the material is supposed to be in a degenerate state with a zero point energy high compared to thermal energies of even 10^7 degrees, and such that the pressure is determined essentially by the density only and not by the temperature, still it would fail completely to describe a normal main sequence star, in which on the basis of the Eddington model the stellar material is nondegenerate, and the existence of energy sources and of the consequent temperature and pressure gradients plays an important part in determining the equilibrium conditions. The stability of a model in which the energy sources have to be taken into account is known to depend also on the temperature sensitivity of the energy sources and on the presence or absence of a time-lag in their response to temperature changes. However, if the view which seems plausible at present is adopted that the principal sources of stellar energy, at least in main sequence stars, are thermonuclear reactions, then the limiting case considered by Landau again becomes of interest in the discussion of what will eventually happen to a normal main sequence star after all the elements available for thermonuclear reactions are used up. Landau showed that for a model consisting of a cold degenerate Fermi gas there exist no stable equilibrium configurations for

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J. Robert Oppenheimer

George Volkoff

“The question of what happens…remains unanswered.”

J. Robert Oppenheimer

J. Robert Oppenheimer

Hartland Snyder

1 September 1939

SEPTEMBER 1, 1939 PHYSICAL REVIEW VOLUME 56

On Continued Gravitational Contraction

J. R. Oppenheimer and H. Snyder
University of California, Berkeley, California

(Received July 10, 1939)

When all thermonuclear sources of energy are exhausted a sufficiently heavy star will collapse. Unless fission due to rotation, the radiation of mass, or the blowing off of mass by radiation, reduce the star's mass to the order of that of the sun, this contraction will continue indefinitely. In the present paper we study the solutions of the gravitational field equations which describe this process. In I, general and qualitative arguments are given on the behavior of the metrical tensor as the contraction progresses: the radius of the star approaches asymptotically its gravitational radius; light from the surface of the star is progressively reddened, and can escape over a progressively narrower range of angles. In II, an analytic solution of the field equations confirming these general arguments is obtained for the case that the pressure within the star can be neglected. The total time of collapse for an observer comoving with the stellar matter is finite, and for this idealized case and typical stellar masses, of the order of a day; an external observer sees the star asymptotically shrinking to its gravitational radius.

I

RECENTLY it has been shown[1] that the general relativistic field equations do not possess any static solutions for a spherical distribution of cold neutrons if the total mass of the neutrons is greater than $\sim 0.7\odot$. It seems of interest to investigate the behavior of nonstatic solutions of the field equations.

In this work we will be concerned with stars which have large masses, $>0.7\odot$, and which have used up their nuclear sources of energy. A star under these circumstances would collapse under the influence of its gravitational field and release energy. This energy could be divided into four parts: (1) kinetic energy of motion of the particles in the star, (2) radiation, (3) potential and kinetic energy of the outer layers of the star which could be blown away by the radiation, (4) rotational energy which could divide the star into two or more parts. If the mass of the original star were sufficiently small, or if enough of the star could be blown from the surface by radiation, or lost directly in radiation, or if the angular momentum of the star were great enough to split it into small fragments, then the remaining matter could form a stable static distribution, a white dwarf star. We consider the case where this cannot happen.

If then, for the late stages of contraction, we can neglect the gravitational effect of any escaping radiation or matter, and may still neglect the deviations from spherical symmetry

[1] J. R. Oppenheimer and G. M. Volkoff, Phys. Rev. **55**, 374 (1939).

J. Robert Oppenheimer

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I

RECENTLY it has been shown[1] that the general relativistic field equations do not possess any static solutions for a spherical distribution of cold neutrons if the total mass of the neutrons is greater than $\sim 0.7\odot$. It seems of interest to investigate the behavior of nonstatic solutions of the field equations.

In this work we will be concerned with stars which have large masses, $>0.7\odot$, and which have used up their nuclear sources of energy. A star under these circumstances would collapse under the influence of its gravitational field and release energy. This energy could be divided into four parts: (1) kinetic energy of motion of the particles in the star, (2) radiation, (3) potential and kinetic energy of the outer layers of the star which could be blown away by the radiation, (4) rotational energy which could divide the star into two or more parts. If the mass of the original star were sufficiently small, or if enough of the star could be blown from the surface by radiation, or lost directly in radiation, or if the angular momentum of the star were great enough to split it into small fragments, then the remaining matter could form a stable static distribution, a white dwarf star. We consider the case where this cannot happen.

If then, for the late stages of contraction, we can neglect the gravitational effect of any escaping radiation or matter, and may still neglect the deviations from spherical symmetry

[1] J. R. Oppenheimer and G. M. Volkoff, Phys. Rev. 55, 374 (1939).

"The most daring and uncannily prophetic paper ever published in the field" — Werner Israel

J. Robert Oppenheimer

Hartland Snyder

The Mechanism of Nuclear Fission

NIELS BOHR
University of Copenhagen, Copenhagen, Denmark, and The Institute for Advanced Study, Princeton, New Jersey

AND

JOHN ARCHIBALD WHEELER
Princeton University, Princeton, New Jersey

(Received June 28, 1939)

On the basis of the liquid drop model of atomic nuclei, an account is given of the mechanism of nuclear fission. In particular, conclusions are drawn regarding the variation from nucleus to nucleus of the critical energy required for fission, and regarding the dependence of fission cross section for a given nucleus on energy of the exciting agency. A detailed discussion of the observations is presented on the basis of the theoretical considerations. Theory and experiment fit together in a reasonable way to give a satisfactory picture of nuclear fission.

INTRODUCTION

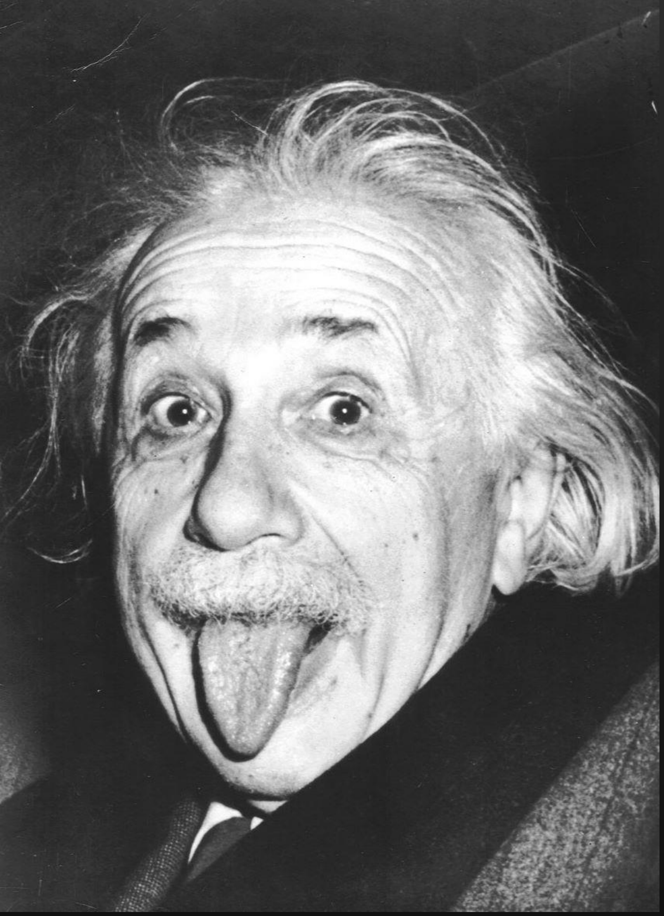
THE discovery by Fermi and his collaborators that neutrons can be captured by heavy nuclei to form new radioactive isotopes led especially in the case of uranium to the interesting finding of nuclei of higher mass and charge number than hitherto known. The pursuit of these investigations, particularly through the work of Meitner, Hahn, and Strassmann as well as Curie and Savitch, brought to light a number of unsuspected and startling results and finally led Hahn and Strassmann[1] to the discovery that from uranium elements of much smaller atomic weight and charge are also formed.

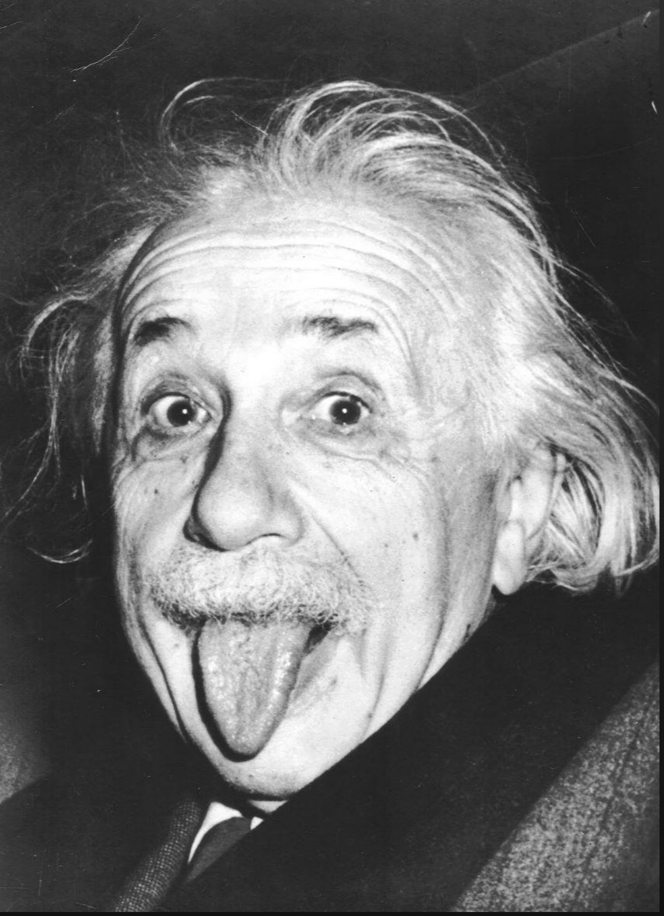
The new type of nuclear reaction thus discovered was given the name "fission" by Meitner and Frisch,[2] who on the basis of the liquid drop model of nuclei emphasized the analogy of the process concerned with the division of a fluid sphere into two smaller droplets as the result of a deformation caused by an external disturbance. In this connection they also drew attention to the fact that just for the heaviest nuclei the mutual repulsion of the electrical charges will to a large extent annul the effect of the short range nuclear forces, analogous to that of surface tension, in opposing a change of shape of the nucleus. To produce a critical deformation will therefore require only a comparatively small energy, and by the subsequent division of the nucleus a very large amount of energy will be set free.

Just the enormous energy release in the fission process has, as is well known, made it possible to observe these processes directly, partly by the great ionizing power of the nuclear fragments, first observed by Frisch[3] and shortly afterwards independently by a number of others, partly by the penetrating power of these fragments which allows in the most efficient way the separation from the uranium of the new nuclei formed by the fission.[4] These products are above all characterized by their specific beta-ray activities which allow their chemical and spectrographic identification. In addition, however, it has been found that the fission process is accompanied by an emission of neutrons, some of which seem to be directly associated with the fission, others associated with the subsequent beta-ray transformations of the nuclear fragments.

In accordance with the general picture of nuclear reactions developed in the course of the last few years, we must assume that any nuclear transformation initiated by collisions or irradiation takes place in two steps, of which the first is the formation of a highly excited compound nucleus with a comparatively long lifetime, while

[1] O. Hahn and F. Strassmann, Naturwiss. **27**, 11 (1939); see, also, P. Abelson, Phys. Rev. **55**, 418 (1939).
[2] L. Meitner and O. R. Frisch, Nature **143**, 239 (1939).
[3] O. R. Frisch, Nature **143**, 276 (1939); G. K. Green and Luis W. Alvarez, Phys. Rev. **55**, 417 (1939); R. D. Fowler and R. W. Dodson, Phys. Rev. **55**, 418 (1939); R. B. Roberts, R. C. Meyer and L. R. Hafstad, Phys. Rev. **55**, 417 (1939); W. Jentschke and F. Prankl, Naturwiss. **27**, 134 (1939); H. L. Anderson, E. T. Booth, J. R. Dunning, E. Fermi, G. N. Glasoe and F. G. Slack, Phys. Rev. **55**, 511 (1939).
[4] F. Joliot, Comptes rendus **208**, 341 (1939); L. Meitner and O. R. Frisch, Nature **143**, 471 (1939); H. L. Anderson, E. T. Booth, J. R. Dunning, E. Fermi, G. N. Glasoe and F. G. Slack, Phys. Rev. **55**, 511 (1939).





October 1939
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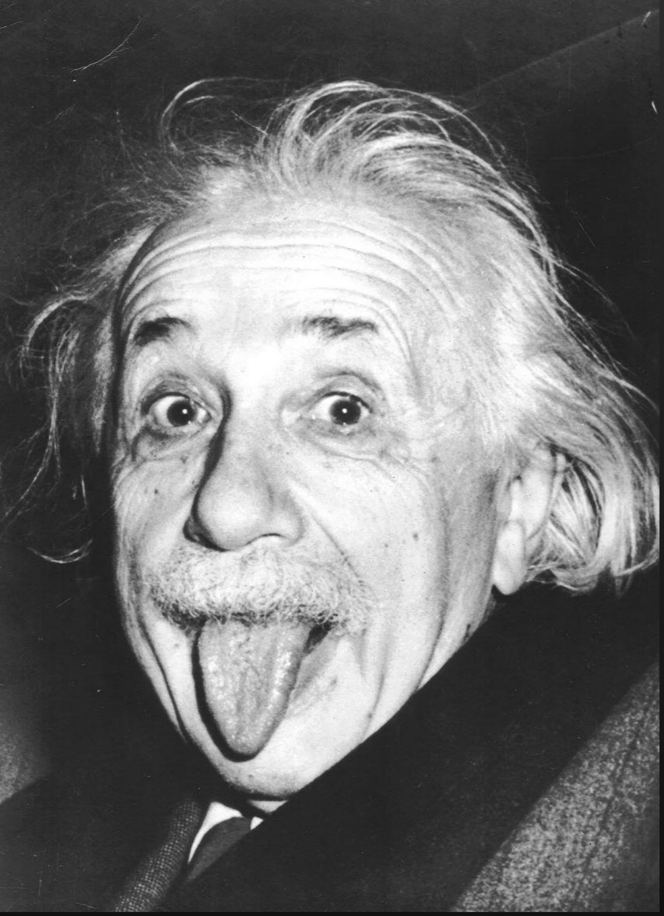
“A clear understanding as to why the ‘Schwarzschild singularities’ do not exist in physical reality.”



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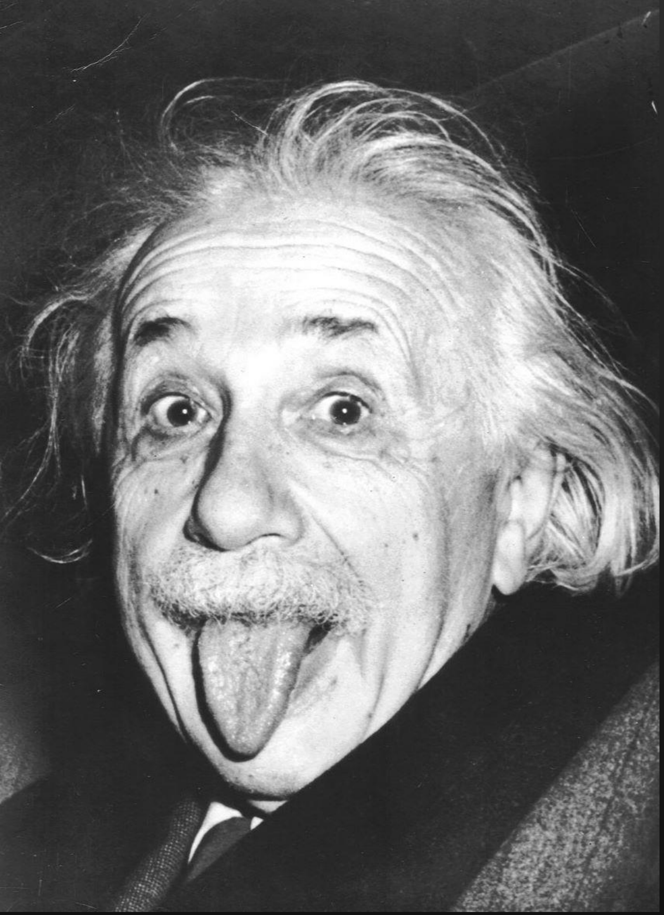
The Conclusion of Historians?



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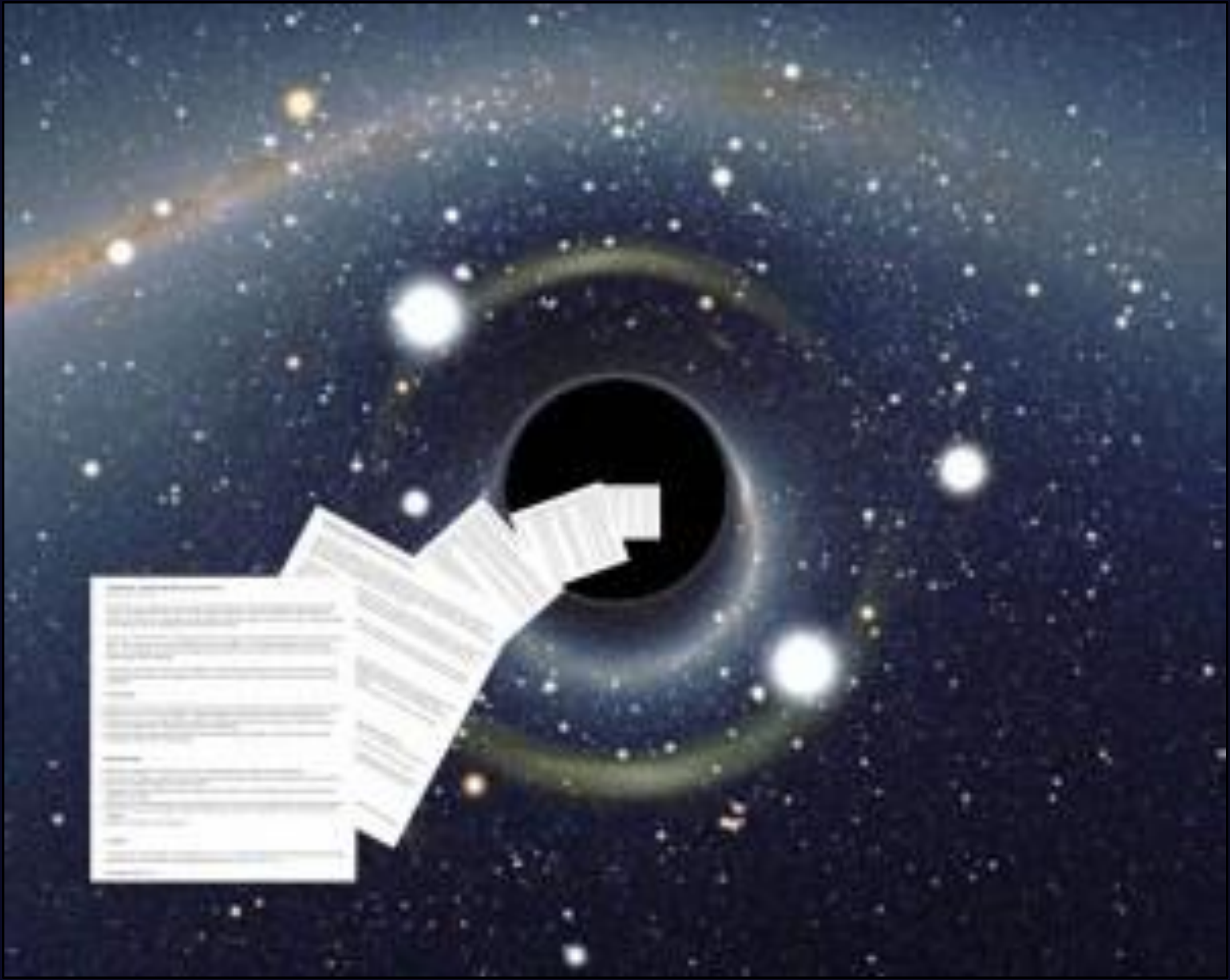
"Strong candidate for…being his worst scientific paper"



Roger Babson

Gravity Research Foundation

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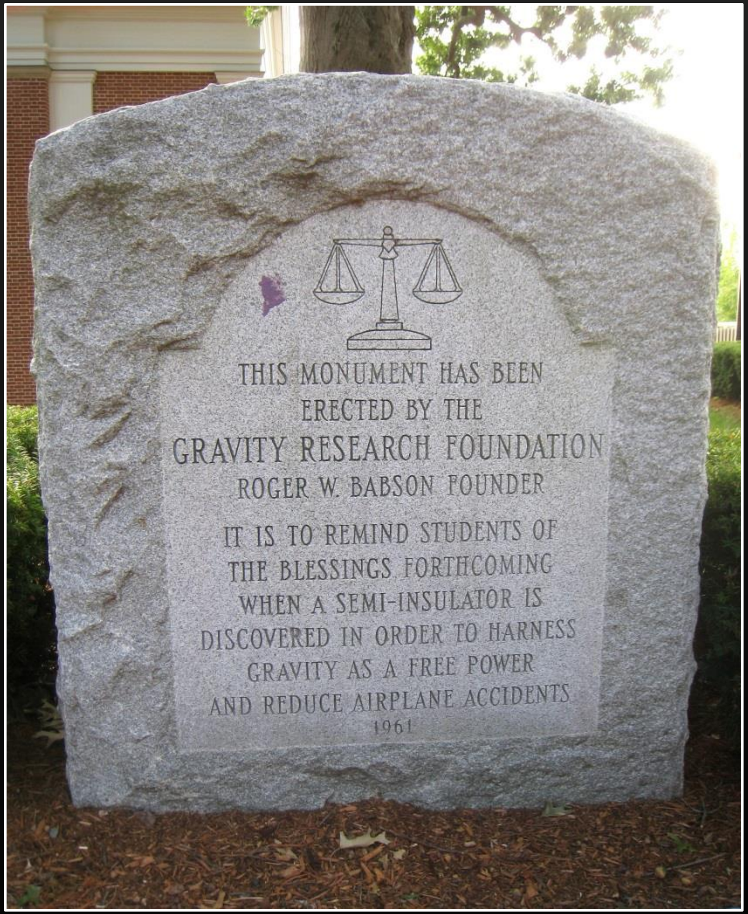
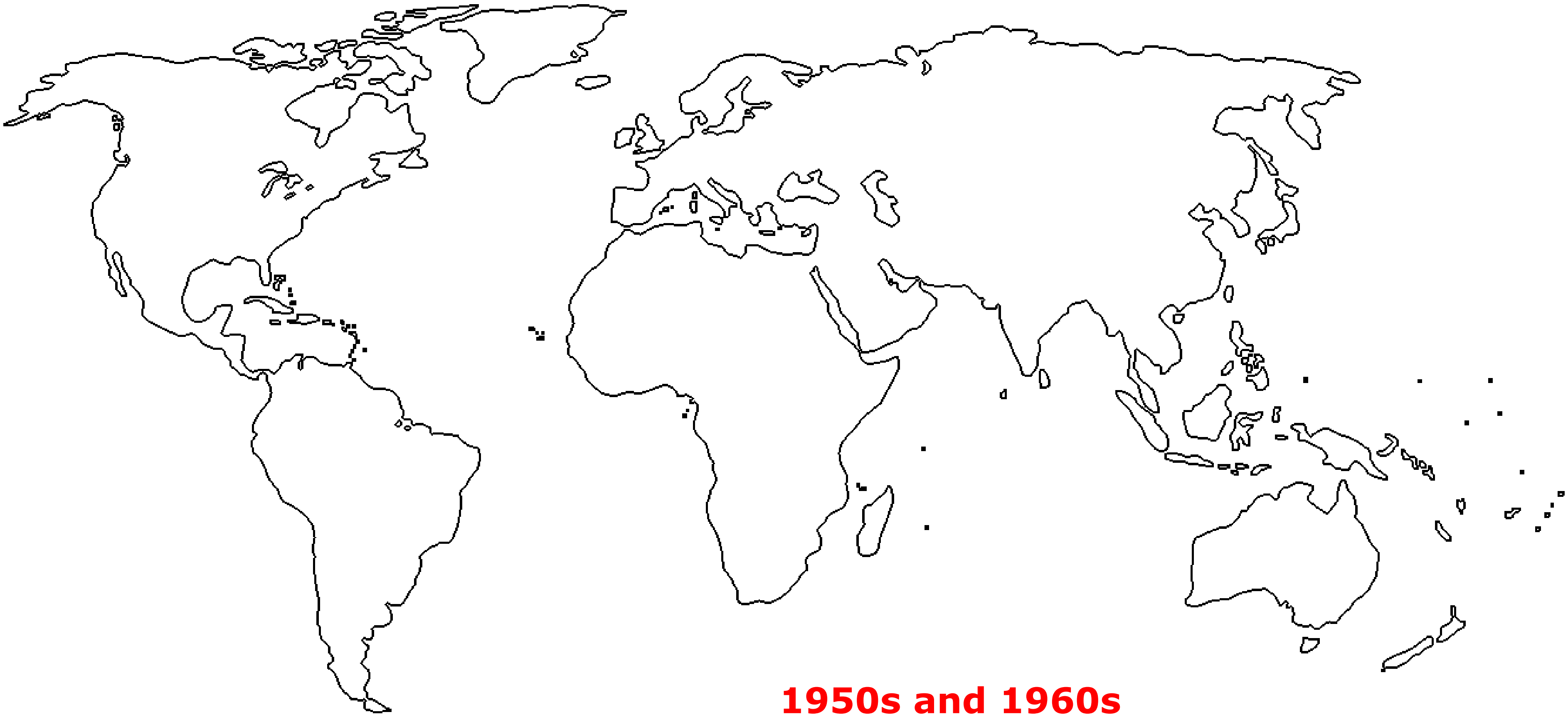
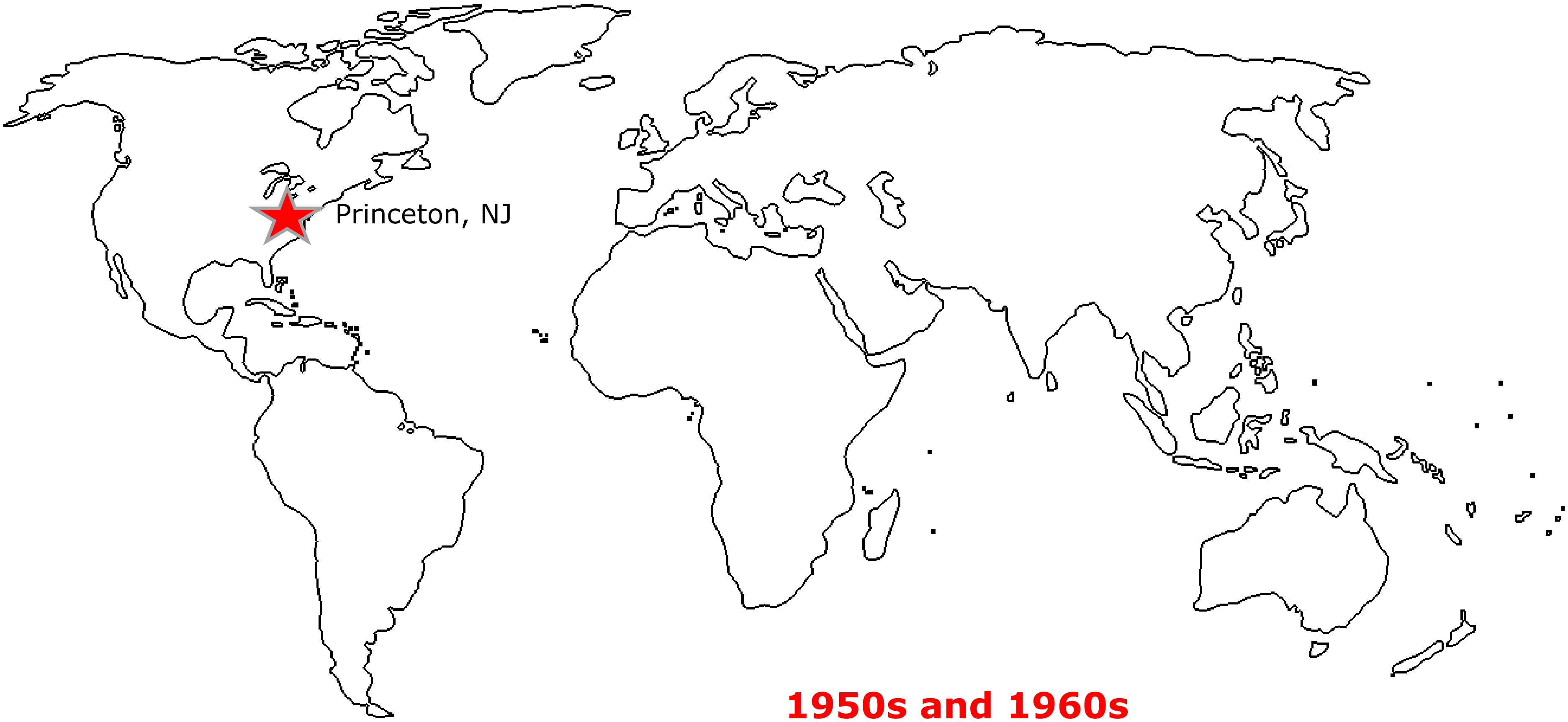
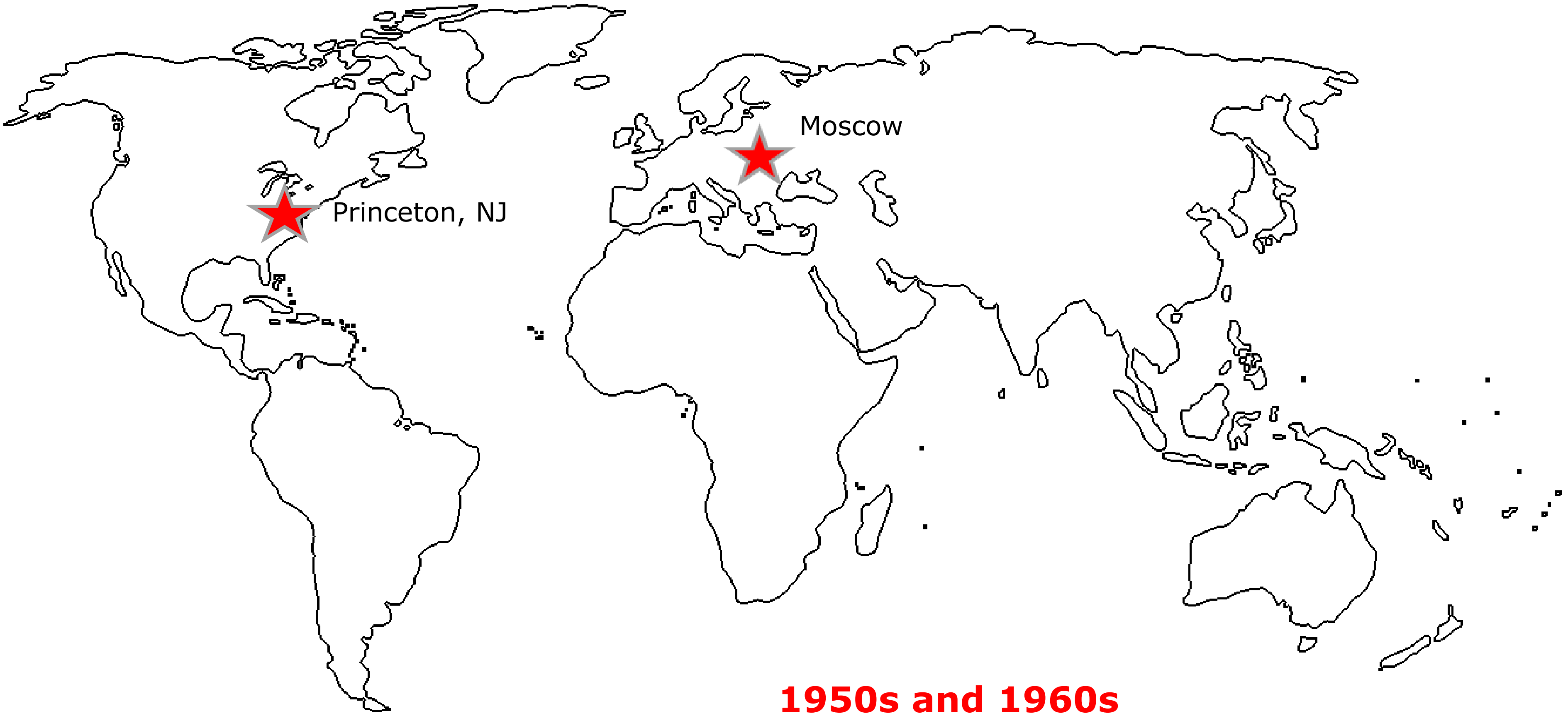


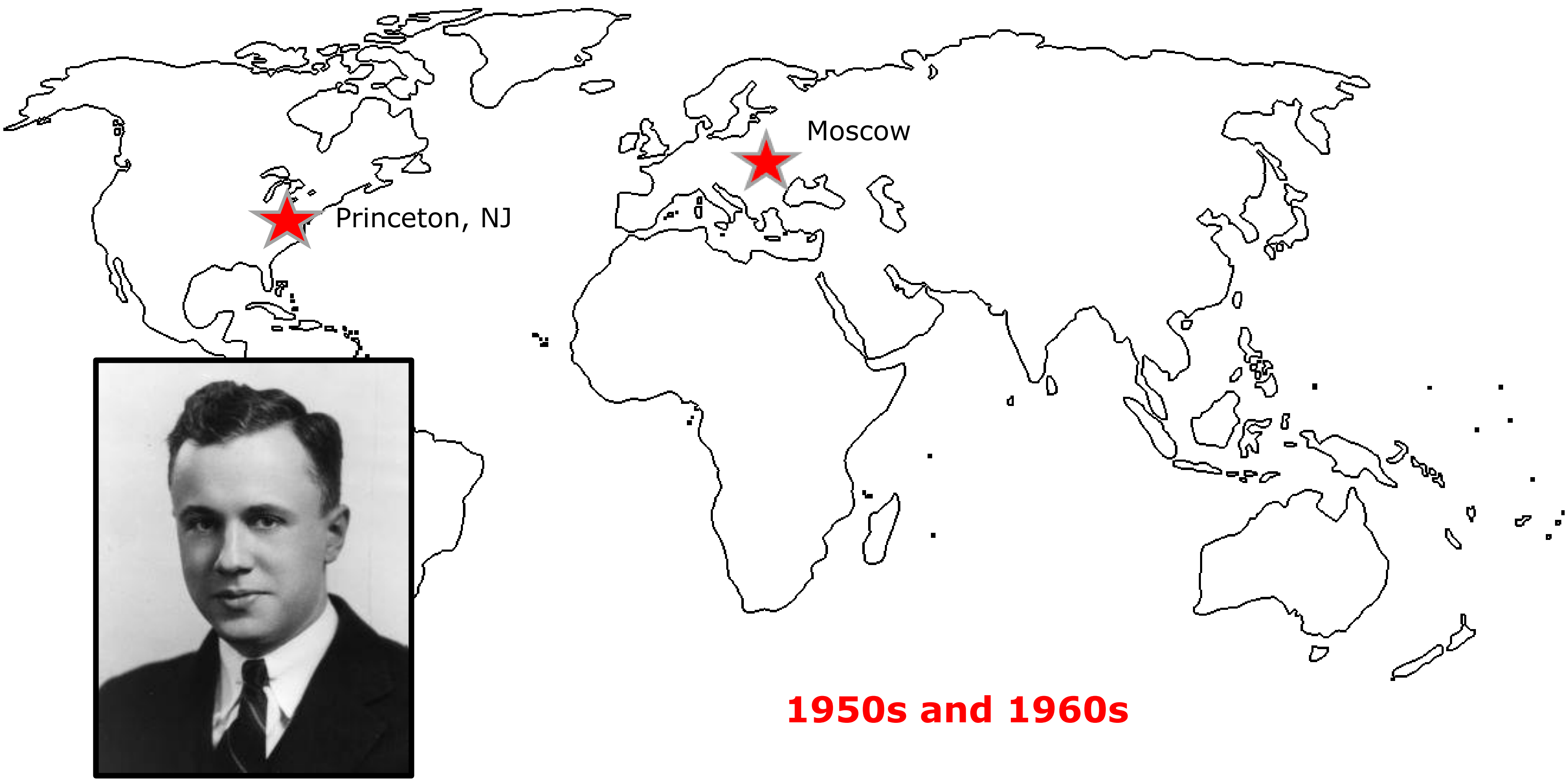


1950s and 1960s


Princeton, NJ
1950s and 1960s



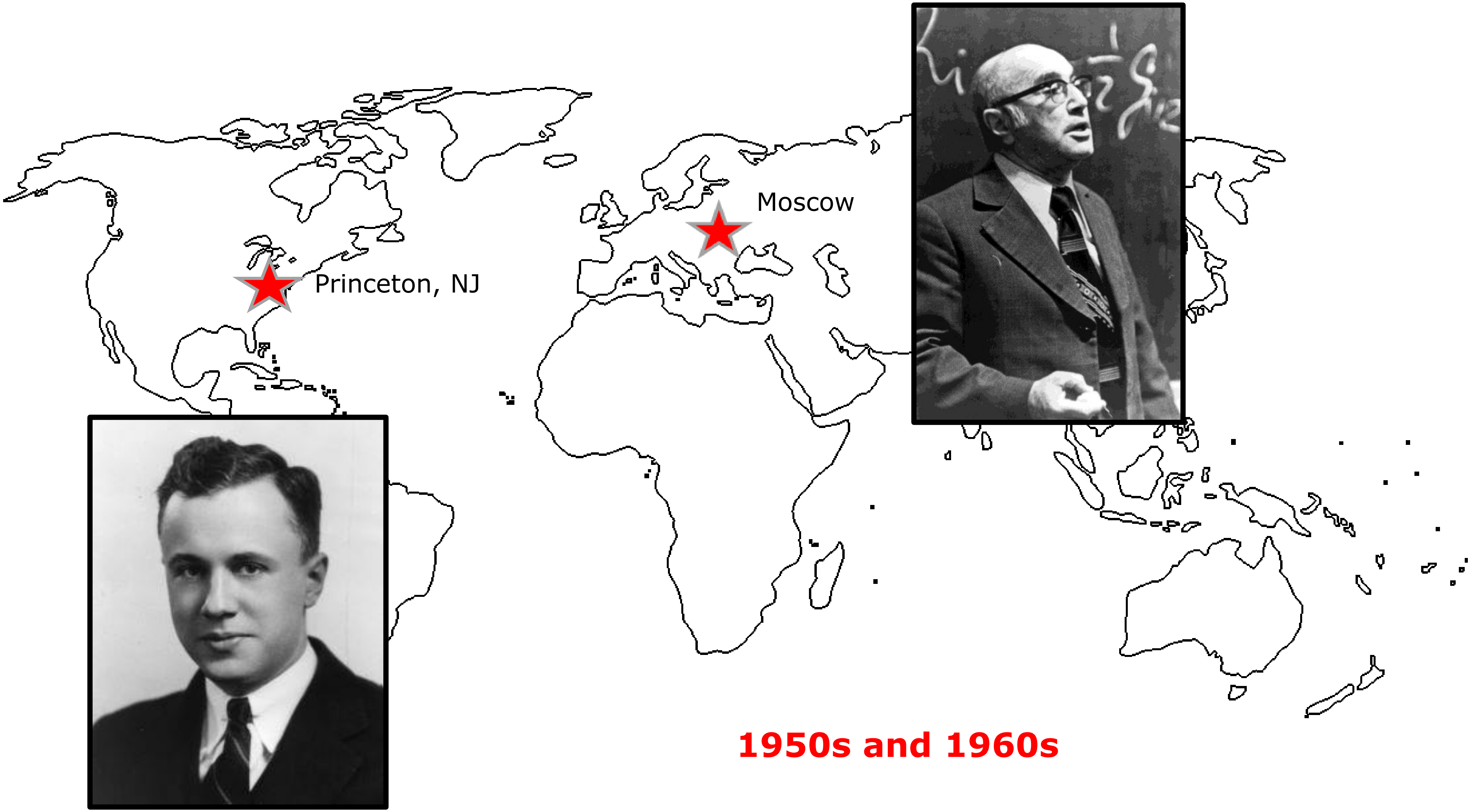
Moscow
Princeton, NJ
1950s and 1960s



John Archibald Wheeler

1950s and 1960s

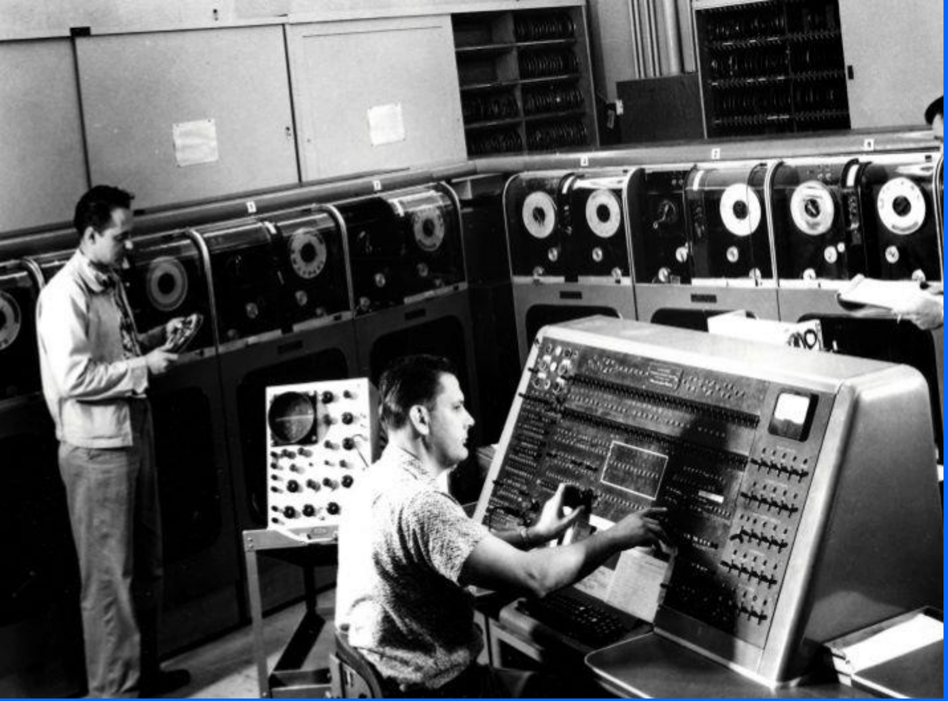
Yakov Zel’dovich

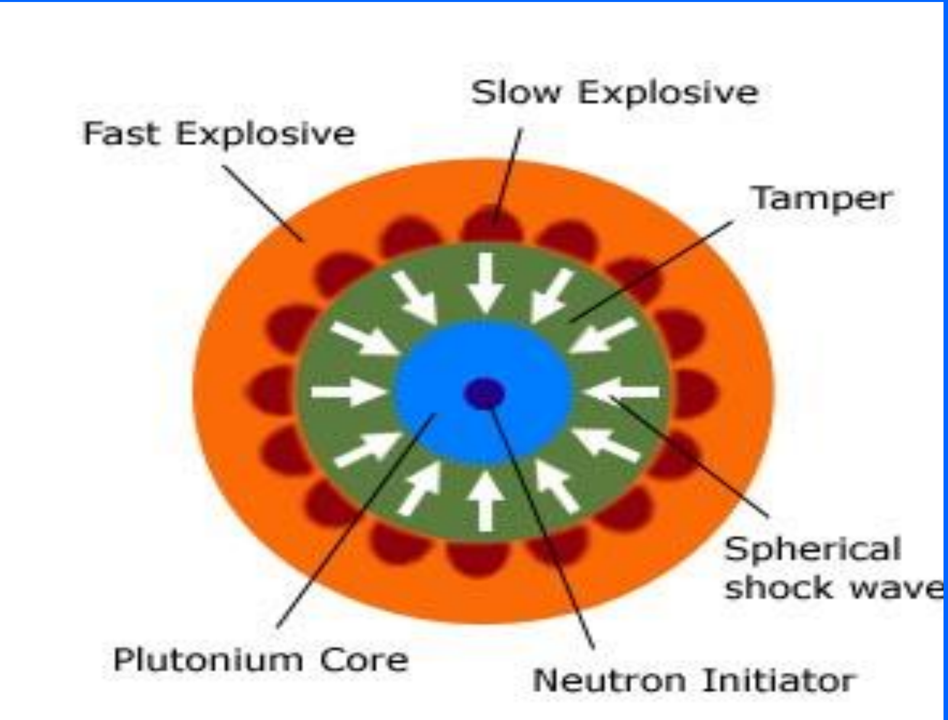


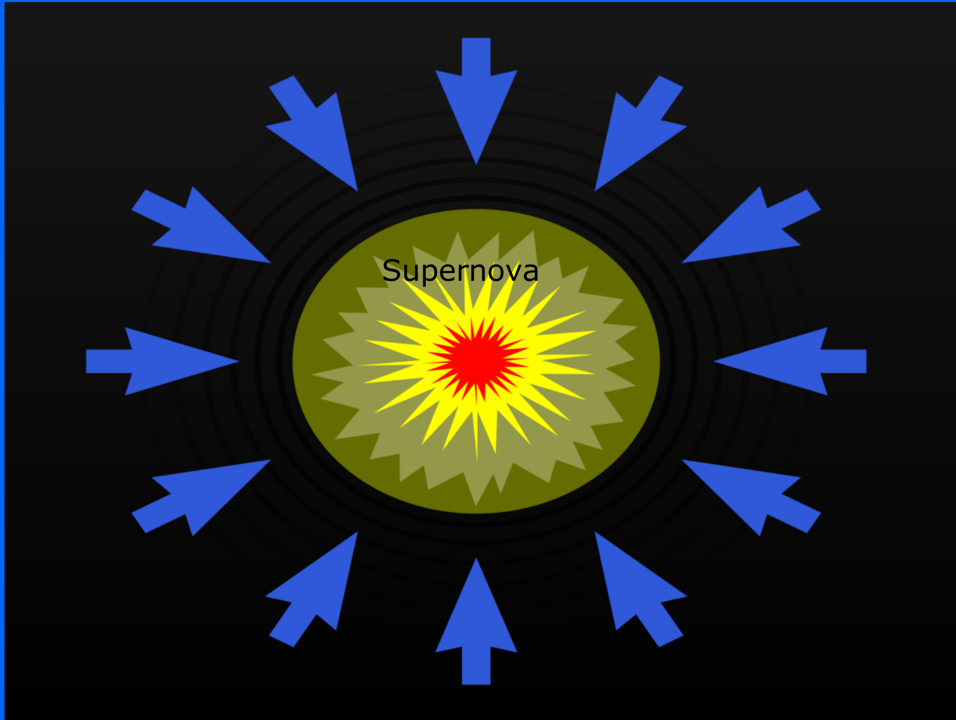
John Archibald Wheeler

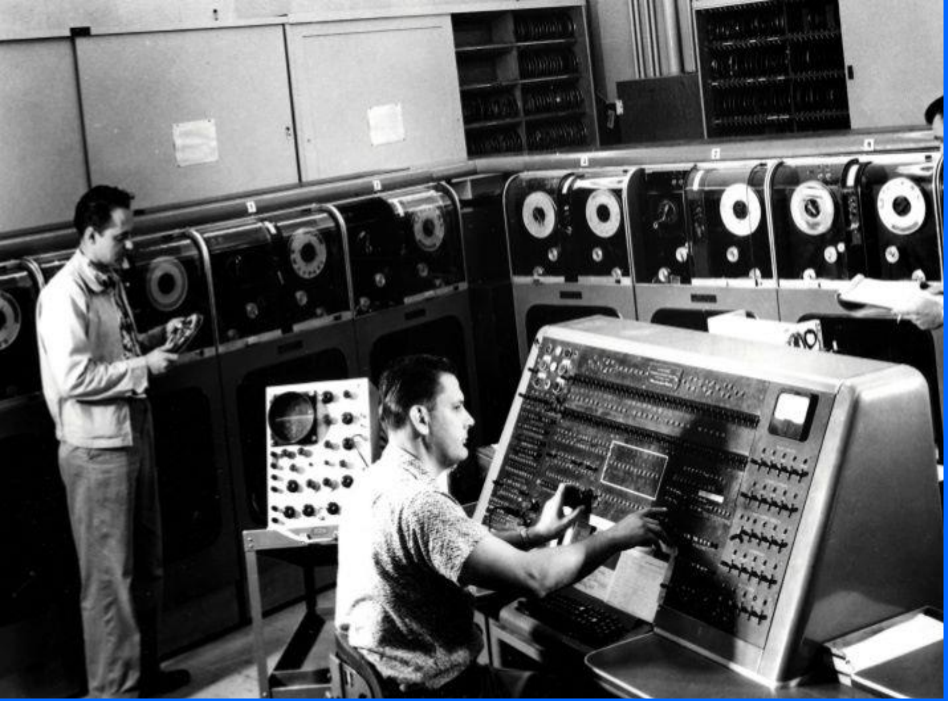
1950s and 1960s

Supernova



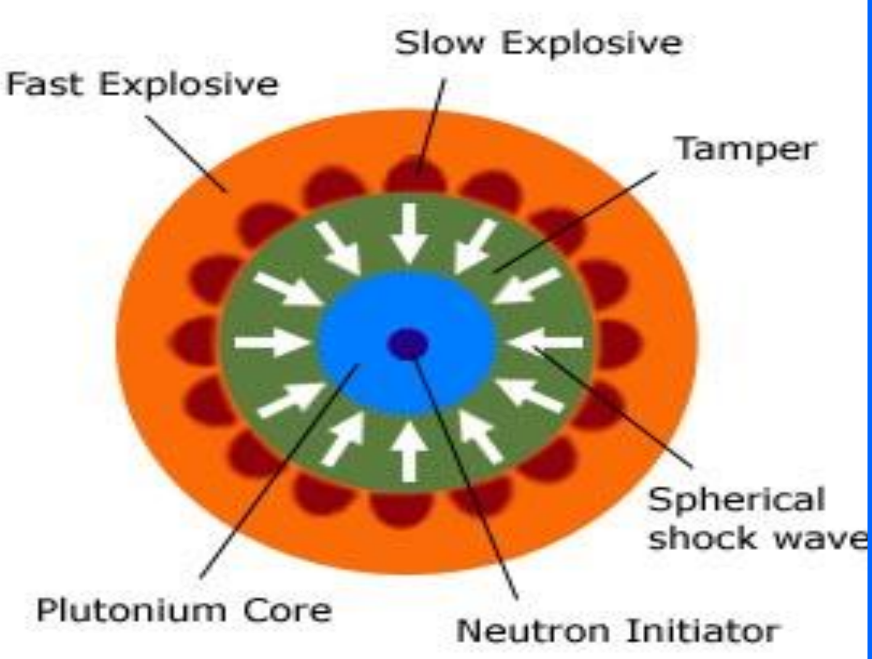

Slow Explosive
Fast Explosive
Tamper
Spherical
shock wave
Plutonium Core
Neutron Initiator

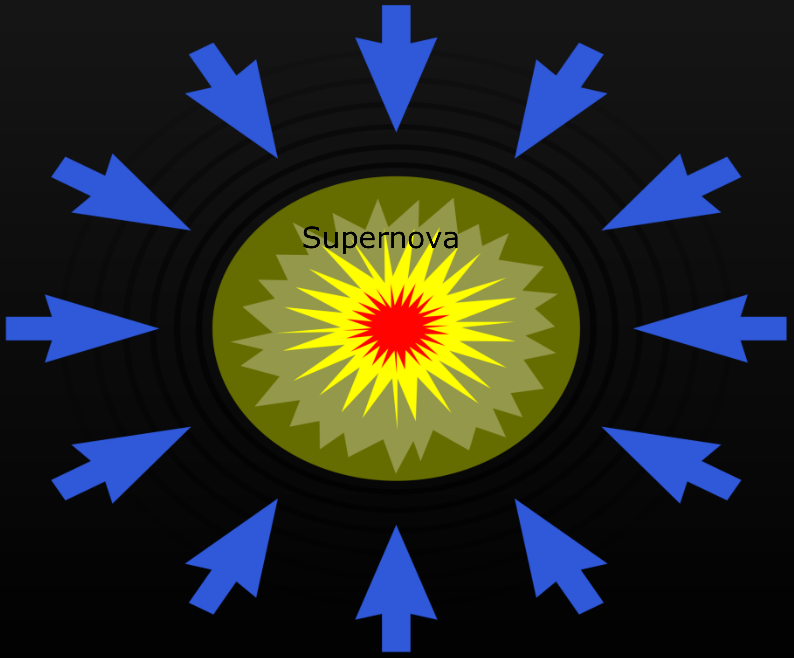

Supernova

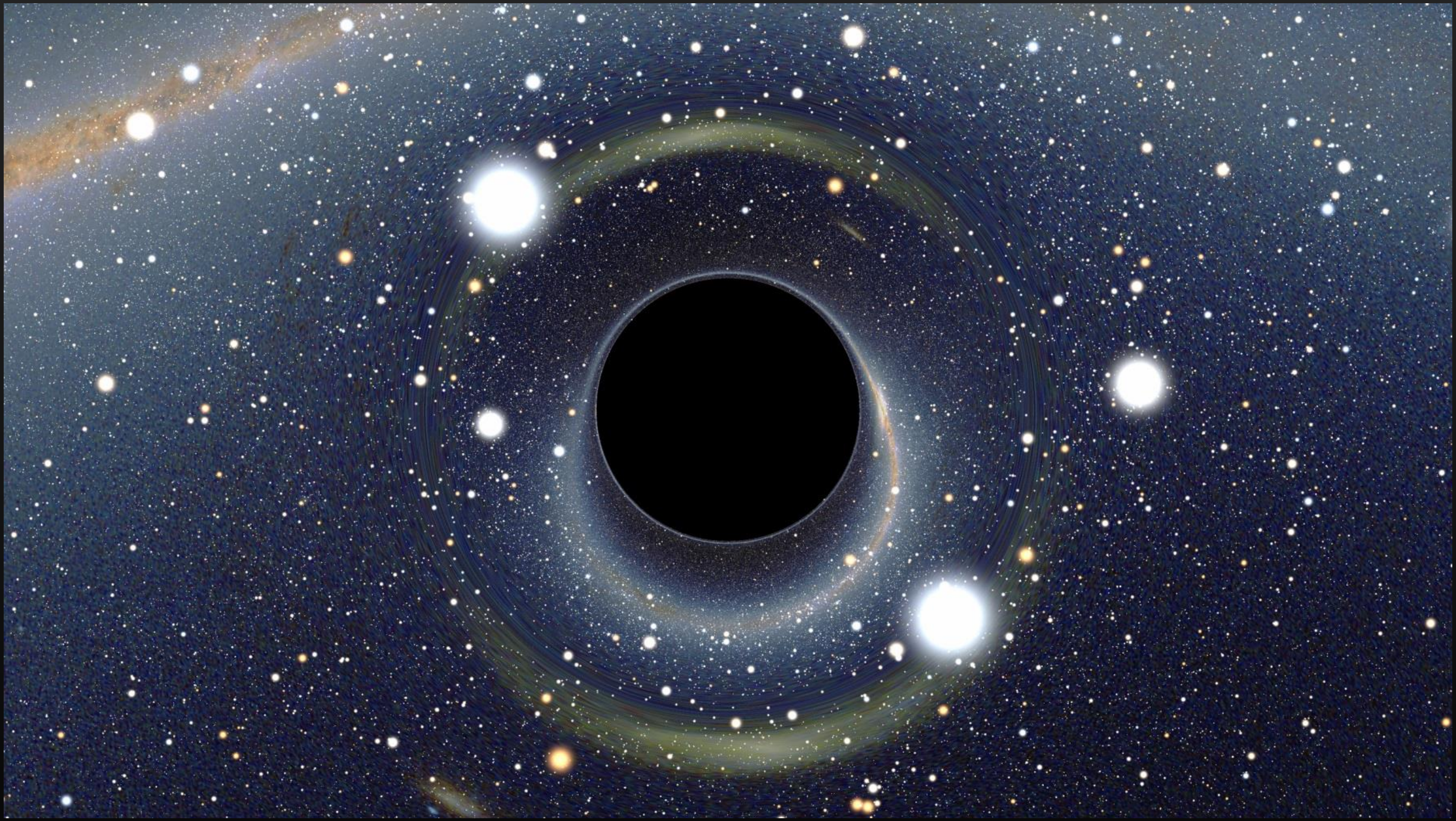


"Zel'dovich one day was writing on the board a formula for the explosion of a star. He gave me a wink, and I winked back. He and I knew it came from another context."

— Wheeler







1963: Quasars

1963: Quasars

1963: Quasars

1967: Pulsars

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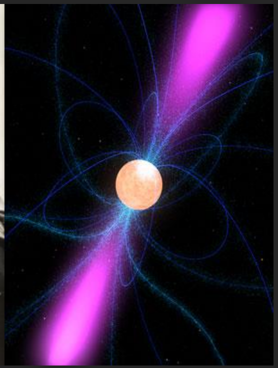


Collapsar

Dark Star

Frozen Star

Gravitationally Collapsed Object

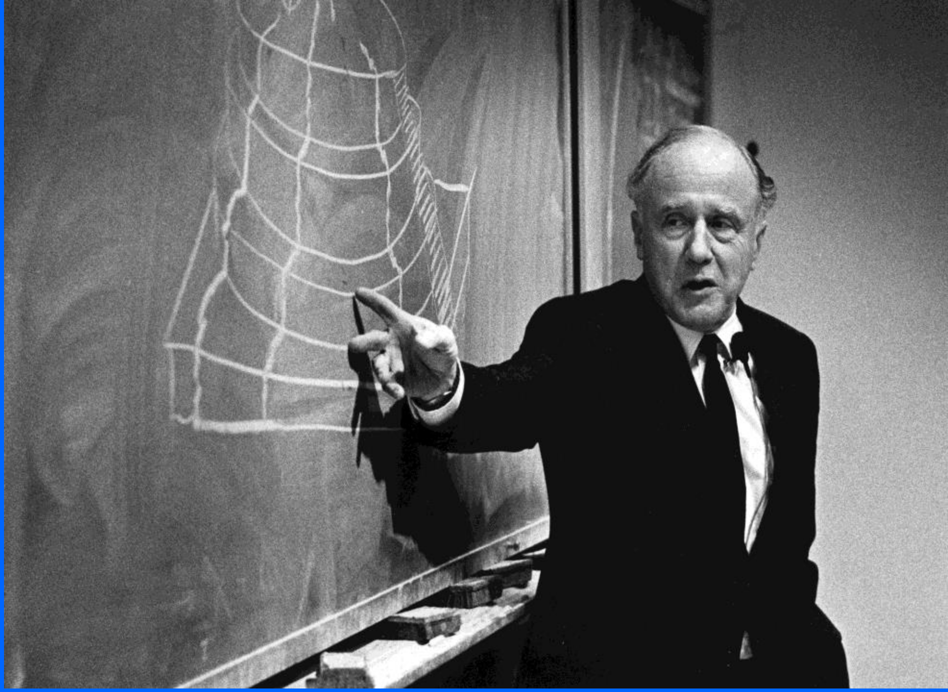
Collapsar

Dark Star

Frozen Star

Gravitationally Collapsed Object

Black Hole



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

AMERICAN SCIENTIST

SPRING · 1968

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By JOHN ARCHIBALD WHEELER

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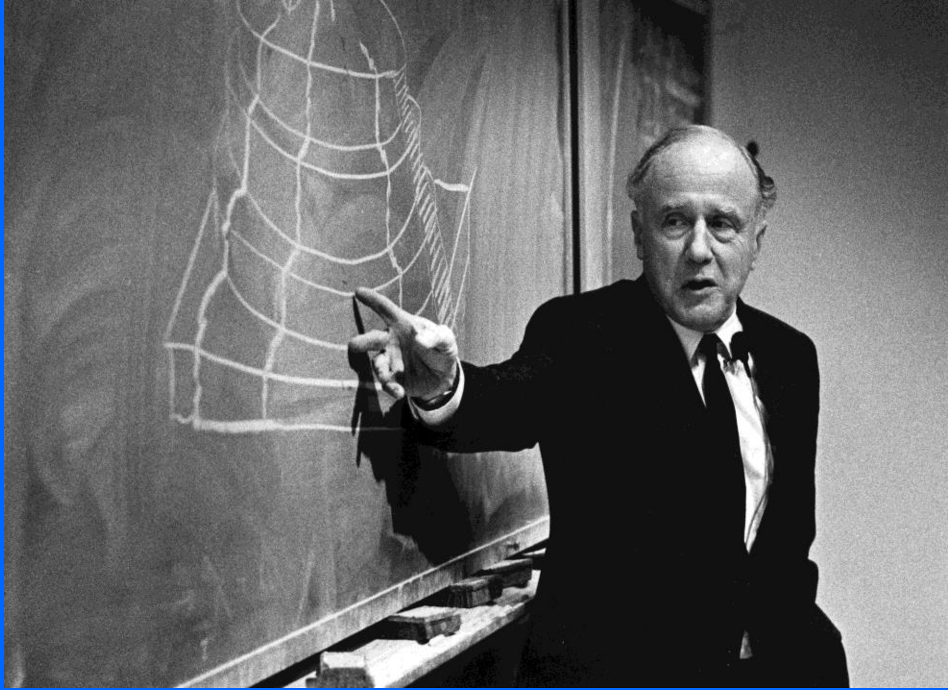

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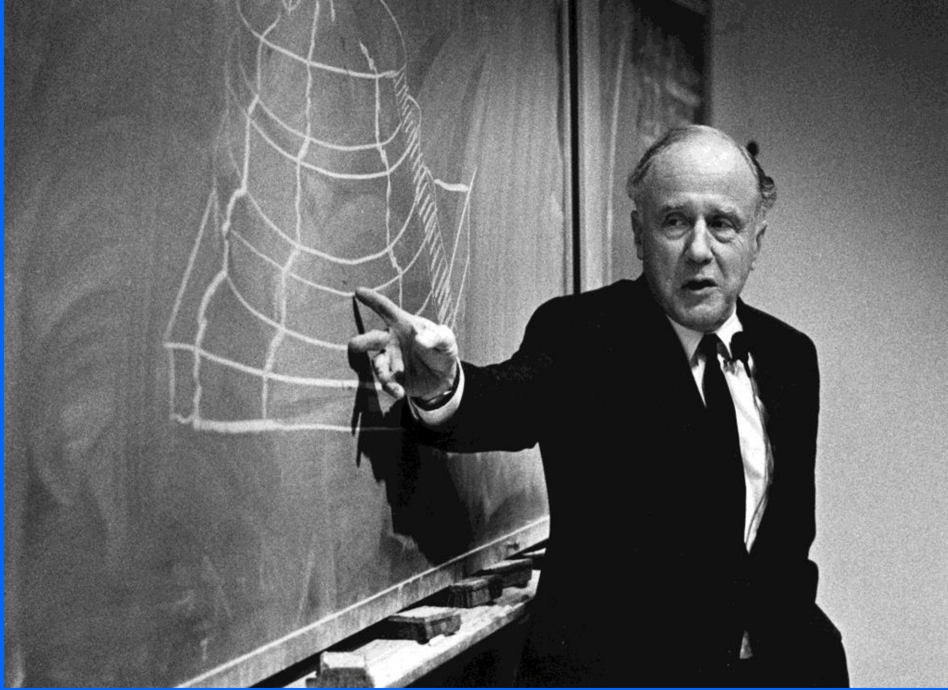

SCIENCE NEWS LETTER *for January 18, 1964*

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

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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.

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.

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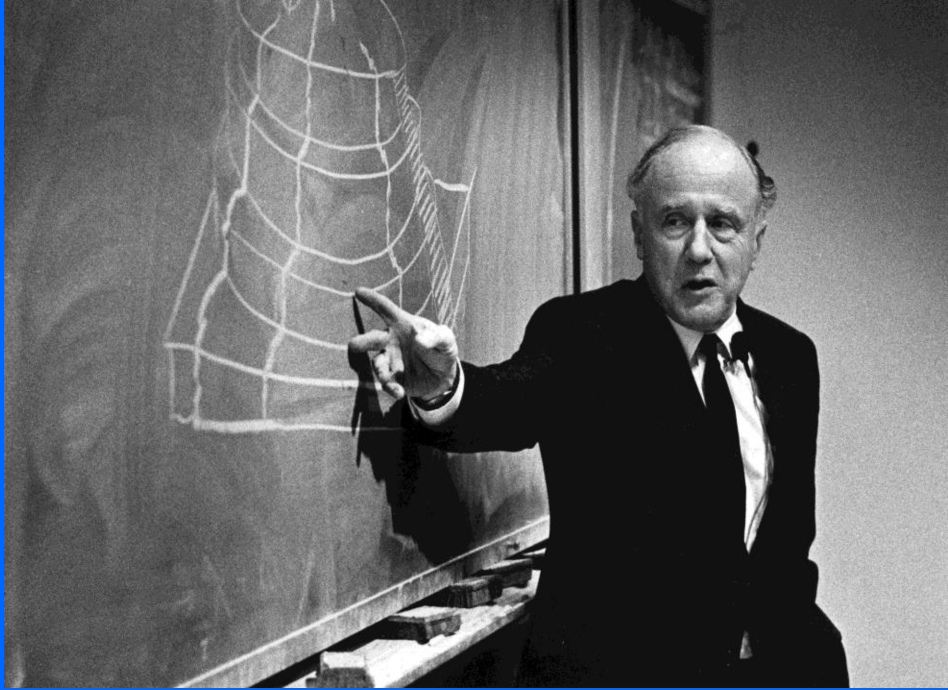

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Scientists have suddenly become aware of some things out there in the skies which they had never noticed before, and they could hardly be more excited if they had just zeroed in on a formation of flying saucers. The excitement is clearly justified: 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.

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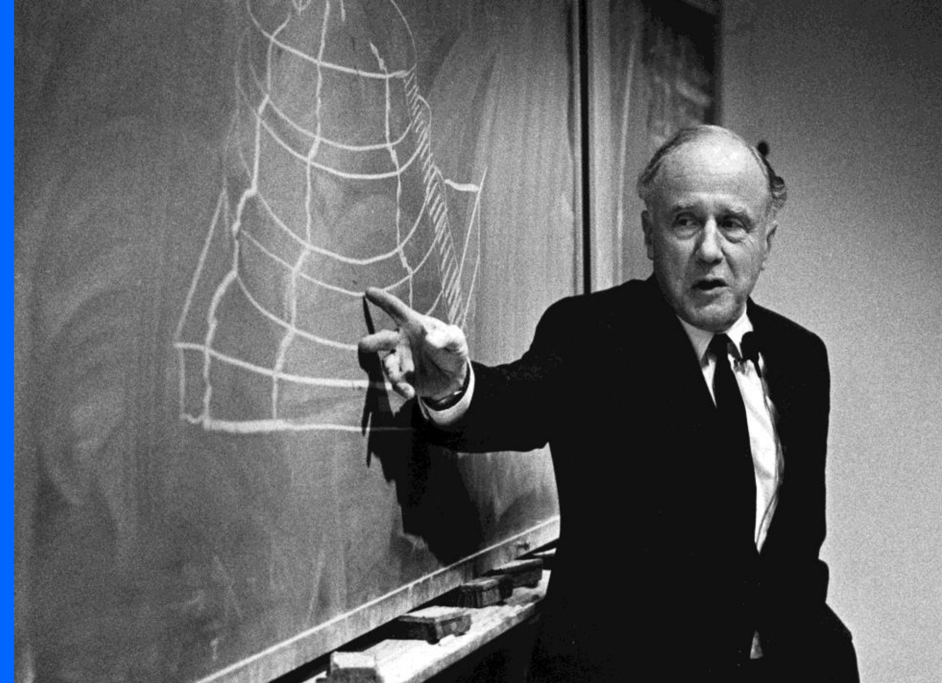

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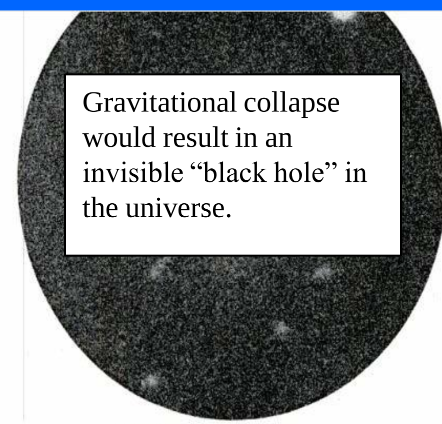

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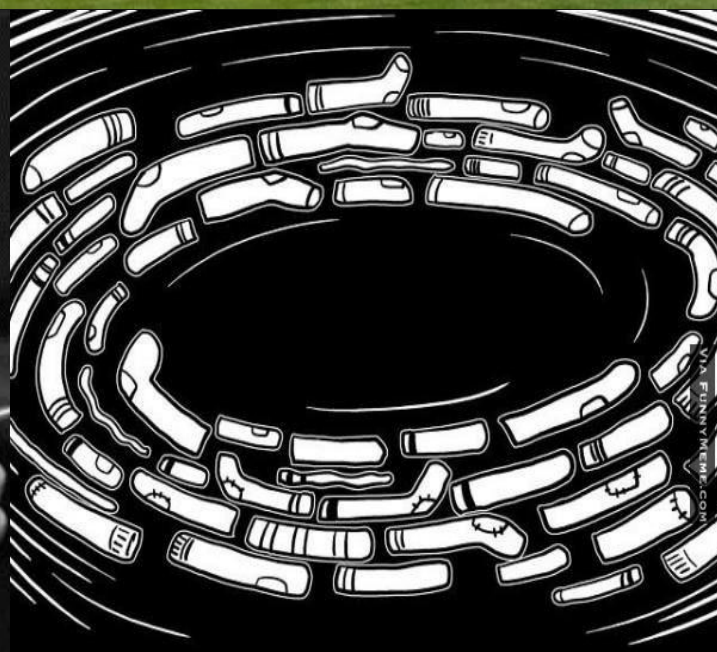

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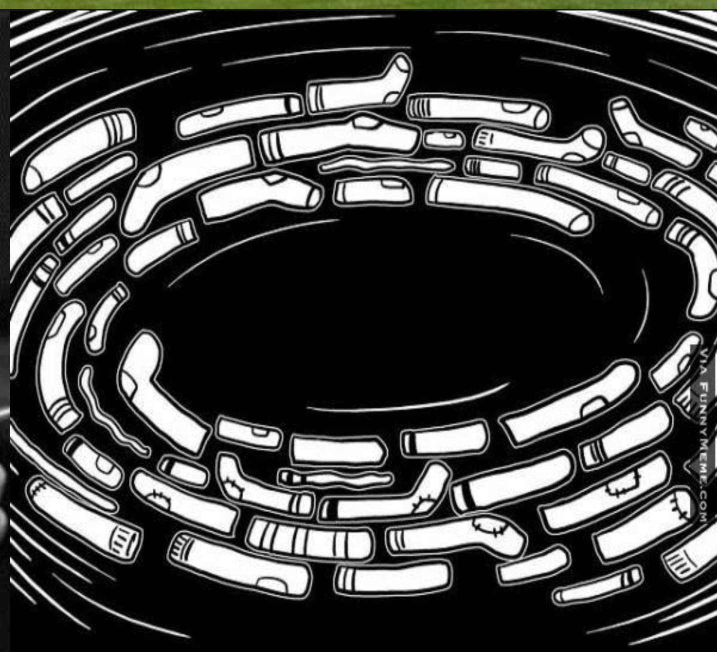

GRAVITATIONAL COLLAPSE WITH ASYMMETRIES

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 $(ds^2)_{\rm Schw}=\alpha dx dy+r^2d\Omega^2$, 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 $r\geqslant 1$.) 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

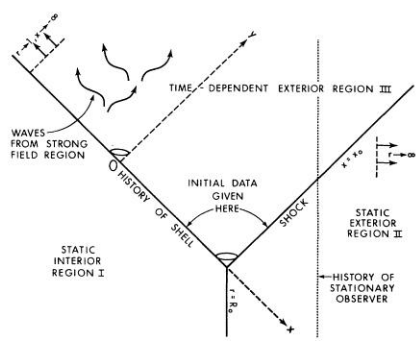

FIG. 1. Space-time diagram for collapsing shell model.

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

Uhuru
Launched 1970

Uhuru
Launched 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, N P-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

Uhuru
Launched 1970

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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 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

Uhuru
Launched 1970

Strange Star Identified as X-Ray Source

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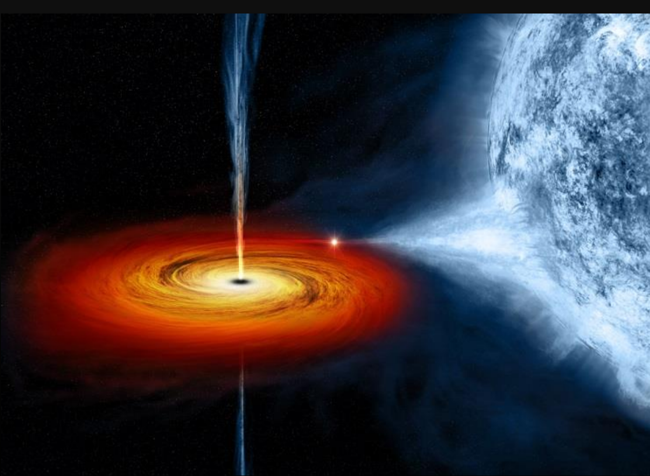
An X-Ray Scanning Satellite May Have Discovered a 'Black Hole' in Space

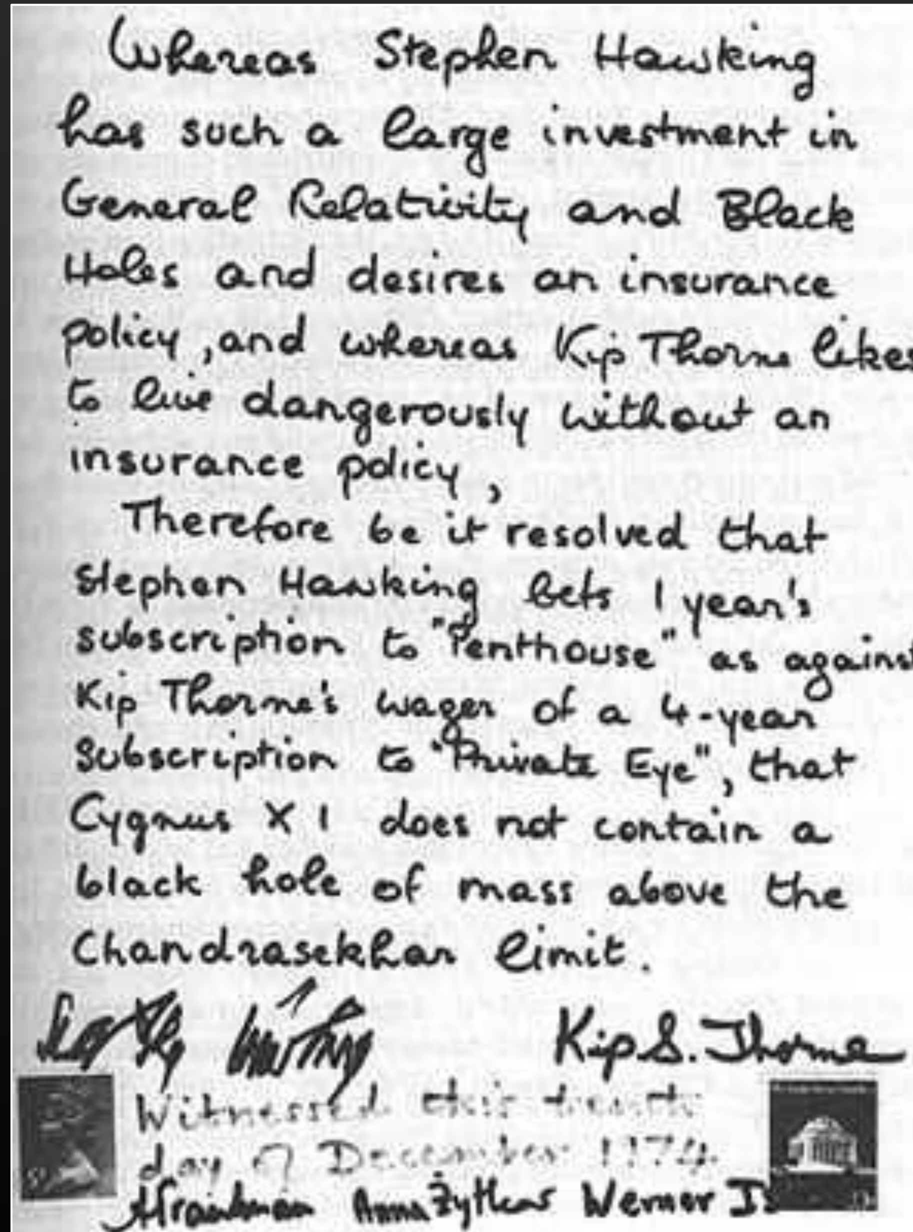
Uhuru
Launched 1970

Cygnus X-1 stealing gas from its giant blue-white companion



Stephen Hawking

Kip Thorne



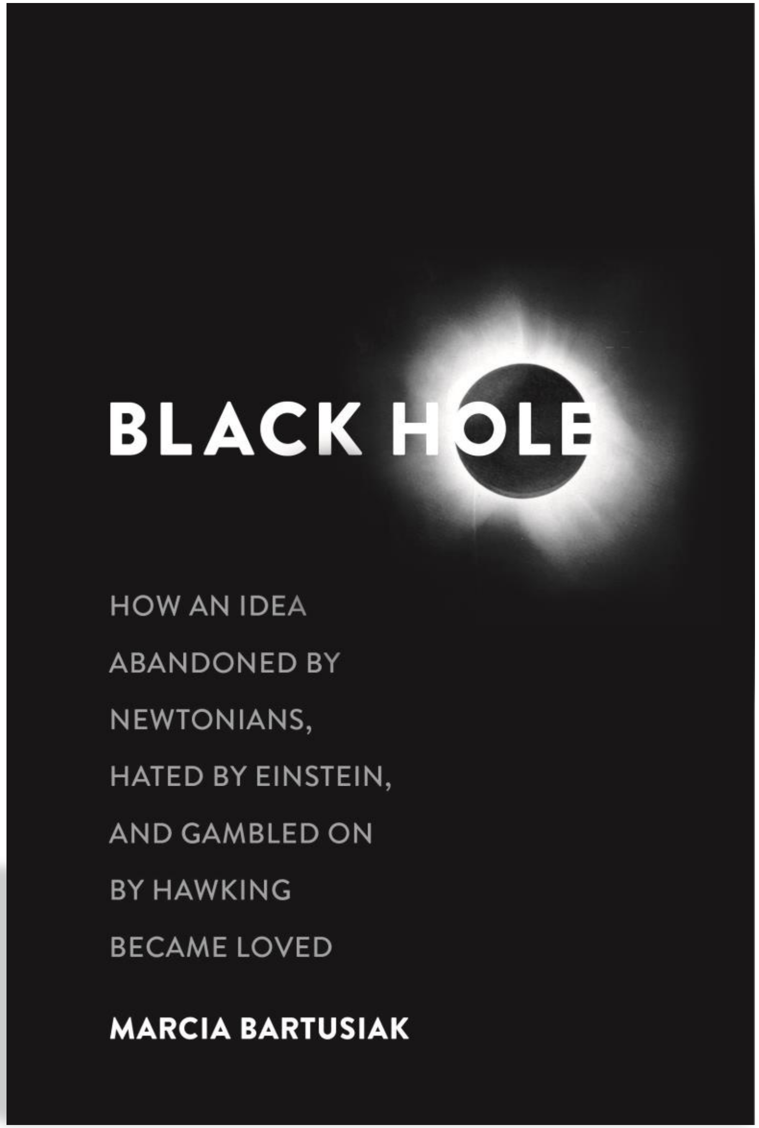
Whereas Stephen Hawking has such a large investment in General Relativity and Black Holes and desires an insurance policy, and whereas Kip Thorne likes to live dangerously without an insurance policy,

Therefore be it resolved that Stephen Hawking bets 1 year's subscription to "Penthouse" as against Kip Thorne's wager of a 4-year subscription to "Private Eye", that Cygnus X1 does not contain a black hole of mass above the Chandrasekhar limit.

Kip S. Thorne

Witnessed this tenth day of December 1974.

Anna Zytkow Werner Is


BLACK HOLE
HOW AN IDEA ABANDONED BY NEWTONIANS, HATED BY EINSTEIN, AND GAMBLED ON BY HAWKING BECAME LOVED
MARCIA BARTUSIAK