Nearly forgotten results in development of physical cosmology

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Steven Weinberg: “I am a physicist, not a historian, but over the years I have become increasingly fascinated by the history of science. It is an extraordinary story, one of the most interesting in human history. Today’s research can be aided and illuminated by a knowledge of its past, and for some scientists knowledge of the history of science helps to motivate resent work.”

References

1. AFZ, Galactic Center Shadows: Beyond the Standard Model, *Physics of Atomic Nuclei* **88***,* 154–170, (2025), https://doi.org/10.1134/S106377882570019X.

2. AFZ, Shadow in the Galactic Center: Theoretical Concept -- Prediction -- Realization, *Natural Science Review* **3**, (2025), arxiv:2506.16927.

Outline

Impact of A. A. Friedmann’s cosmological studies on development of Russian investigations in GR

Achievements of Russian scientists in physical cosmology (Gamow, Shmaonov, Strukov, Gliner and others)

Lemaitre as the Big Bang Father and the discovery of the Hubble – Lemaitre law

BH @ Galactic Center

Country ratings in science

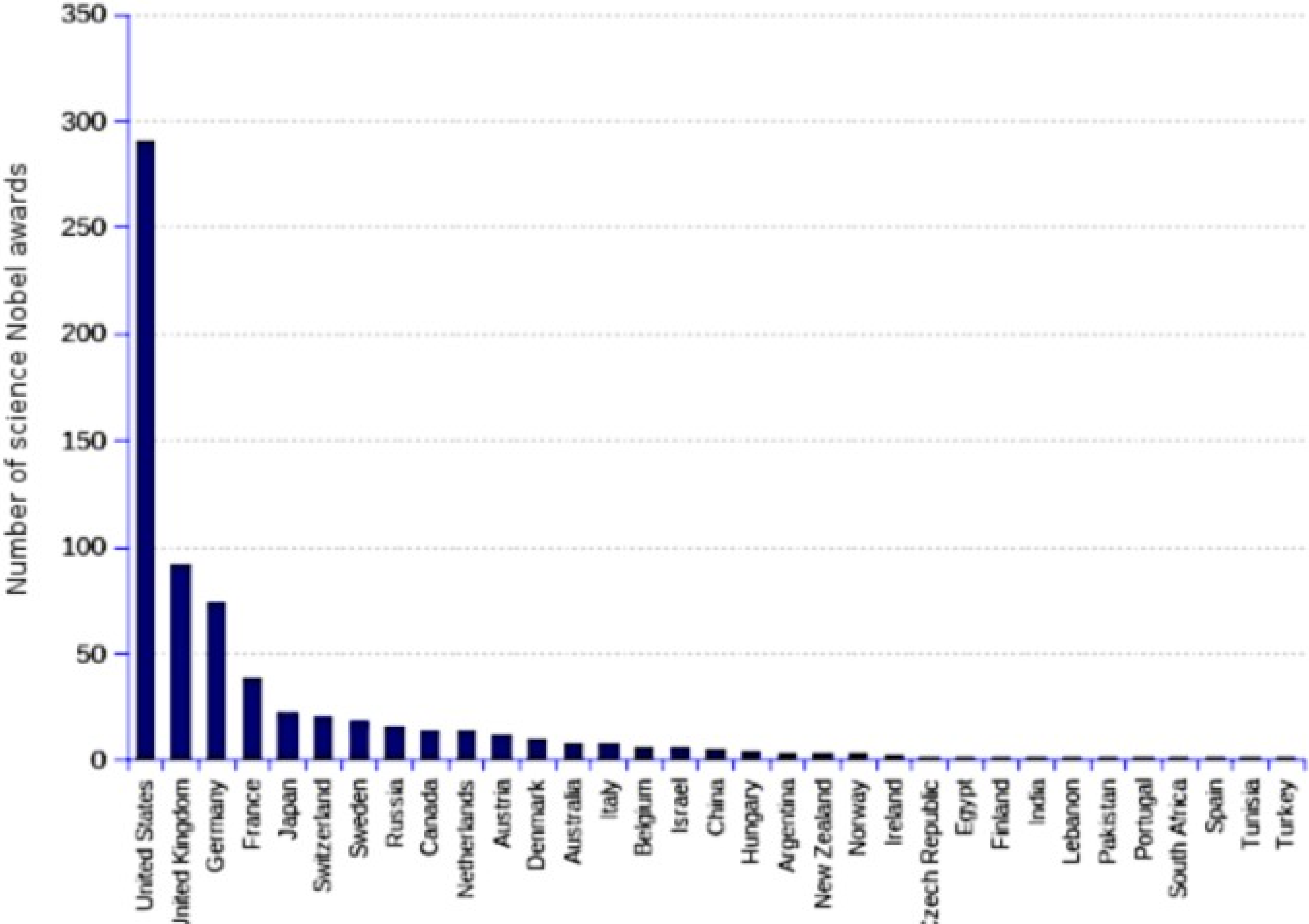
One of the possible options to grade science levels in countries is a number of Nobel prize winners.

However, if we use the criterium there is an official opinion that the Nobel Committee ignores achievements of Soviet (Russian) scientists and therefore, the level of Russian science was underestimated (see, A. Blokh,

“The Soviet Union in the interior of the Nobel Prizes” Fizmatlit, Moscow 2005).

СОВЕТСКИЙ СОЮЗ В ИНТЕРЬЕРЕ НОБЕЛЕВСКИХ ПРЕМИЙ

Science Nobel Prizes by Nation



V. L. Ginzburg: Russian scientists practically did not nominate their compatriots for the Nobel Prizes, and then they said that their outstanding achievements were ignored by the Nobel prize Committee.

For instance, The Bureau of the Department of Physical and Mathematical Sciences of the USSR Academy of Sciences sent an extract from the minutes of the meeting dated November 1, 1955 to the Foreign Department of the USSR Academy of Sciences "On the nomination of Soviet scientists for the Nobel Prize."

The Bureau of the department does not consider it appropriate to nominate Soviet scientists for the Nobel Prize, since, in the opinion of the bureau members, this prize cannot be considered international due to the fact that the Nobel Committee did not consider it tedious to award this prize to outstanding figures of science and culture of our country (D. And Mendeleev, L. N. Tolstoy, A. P. Chekhov, M. Gorky). The Bureau chairman academician M. A. Lavrentiev, the secretary is Candidate of Chemical Sciences A. N. Lobachev

One case of physical discovery combination (Raman) scattering

The combination scattering was discovered independently by G. S. Landsberg and L. I. Mandelstam on 21 February 1928 in Moscow and S. V. Raman and K. S. Krishnan on 28 February 1928 in Calcutta. However, Raman and Krishnan published their paper on 31 March 1928 in Nature, while L-M paper was received by on 12 July 1928 in Zeitschrift für Physik and published in November 1928.

Many Soviet physicists (including V. L. Ginzburg) considered this case as a discriminnation of Soviet physicists since Raman received a Nobel prize in 1930, but Landsberg and Mandelstam not.

Year	Nominee	Nominator	
1930	Chandrasekhara Raman Werner Karl Heisenberg	Jean Perrin	NP in 1926
1930	Grigoriy Landsberg Leonid Mandelstam (Mandelshtam) Chandrasekhara Raman	Orest Khvol'son	
1930	Chandrasekhara Raman Robert Wood	Eugene Bloch	
1930	Robert Wood Chandrasekhara Raman	Niels Bohr	NP in 1922
1930	Chandrasekhara Raman	Prince Louis Victor de Broglie	NP in 1929
1930	Chandrasekhara Raman	Maurice de Broglie	
1930	Chandrasekhara Raman	Richard Pfeiffer	
1930	Chandrasekhara Raman	Ernest Lord Rutherford	NP in 1908
1930	Chandrasekhara Raman	Johannes Stark	NP in 1919
1930	Chandrasekhara Raman	Charles Wison	NP in 1929

	Nominee	Nominator	
1929	Robert Wood Chandrasekhara Raman	Niels Bohr	NP in 1922
1929	Jean Cabannes Chandrasekhara Raman	Charles Fabry	

Year	Nominee	Nominator	
1930	Grigoriy Landsberg Leonid Mandelstam (Mandelshtam) Chandrasekhara Raman	Orest Khvol’son	
1930	Leonid Mandelstam (Mandelshtam)	Nikolay Papaleksi	

GR was born in conversations between A. Einstein and D. Hilbert in November 1915

This interesting correspondence has been was publicly known in 1978

Einstein and Hilbert: Two Months in the History of General Relativity

JOHN EARMAN & CLARK GLYMOUR

Communicated by J.D. NORTH

1. Introduction

The vast majority of current English language textbooks on relativity theory treat, either explicitly or implicitly, the field equations of general relativity as EINSTEIN's equations.[1] By contrast, PAULI[2] credits HILBERT as being co-discover of the field equations.[3] GUTH[4] has claimed that HILBERT deserves no credit since he knew of EINSTEIN's formulation of the field equations before proceeding to an after-the-fact derivation from a variational principle. GUTH's claims have in turn been disputed by MEHRA.[5] Questions about the priority of discoveries are often among the least interesting and least important issues in the history of science, and our main purpose here is to illuminate the development of EINSTEIN's ideas rather than to engage in priority disputes. It turns out, however, that for the crucial period of 1915, these two matters are intimately linked.

EINSTEIN corresponded regularly with MICHELE BESSO, PAUL EHRENFEST, ERWIN FREUNDLICH, H.A. LORENTZ, and ARNOLD SOMMERFELD. But during the period from late October to late November of 1915, the correspondence virtually ceases – in the EINSTEIN Papers at Princeton there are no letters from

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[1] See, for example, C. MØLLER, *The Theory of Relativity* (Oxford: Clarendon Press, 1952); R.C. TOLMAN, *Relativity, Thermodynamics, and Cosmology* (Oxford: Clarendon Press, 1962); S. WEINBERG, *Gravitation and Cosmology* (New York: John Wiley, 1972); and R. ADLER, M. BAZIN & M. SCHIFFER, *Introduction to General Relativity* (New York: McGraw Hill, 1975).

[2] W. PAULI, *Theory of Relativity* (New York: Pergamon Press, 1958), footnote 277, p. 145.

[3] See also H. WEYL, "Zu David Hilberts siebzigstem Geburtstag." *Die Naturwissenschaften*, **20** (1932), 57–58, "50 Jahre Relativitätstheorie," *ibid.* **38** (1951), 73–83;

G. Gamov (Friedmann's student), V.A. Fock (Frederiks's & Friedmann's student)

Two great physicists (George Gamow and Abram Alikhanov) were born at the same day (04.03.1904) in Odessa and Elizavetpol (today Ganja, Azerbaijan). This generation of physicists creates a glory of Russian science.

Former LSU rectors: A. D. Alexandrov (Delaunay (Delone) and Fock's student) and S. P. Merkuriev

International GR Conferences

GRG-0, Bern (1955), Pauli, Fock, Alexandrov

GRG-1 (1957, Chapel Hill, NC, USA), Feynman, Bondi, Weber, Wheeler, De Witt, Bergmann -- The start of GWs race

GRG-3 (1962, Warsaw, Jablonna, Poland)

The First Texas Symposium (1963) – R. Kerr, A. Papapetrou, T. Gold

…………………………………………………………….

…………………………………………………………..

GR0

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63 years since the Jablonna Conference (GR3) and 68 years since the Chapel Hill Conference (GR1)

Gen Relativ Gravit (2014) 46:1718
DOI 10.1007/s10714-014-1718-y

HISTORY

The Jablonna conference on gravitation: a continuing source of inspiration

Marek Demianski

Received: 21 January 2014 / Accepted: 11 March 2014 / Published online: 23 May 2014

First of all I would like to welcome all of you at the main campus of the University of Warsaw—my University. Especially warmly I would like to welcome the youngest participants who for the first time participate in a big international conference. I do understand how you feel, I do understand your anxiety. Fifty one years ago I was able to observe the International Jablonna Conference on General Relativity and Gravitation, that later was classified as the GRG-3 conference. In June of 1962, I got my Master of Science degree in physics. My thesis advisor, Professor Leopold Infeld, was the Chairman of the Local Organizing Committee of the Jablonna conference. Professor Infeld asked me to help with such simple tasks as cleaning the blackboard, make sure that chalk was always available, but also—and this was really important—every morning to collect participants who were staying in hotels in Warsaw into a special coach and bring them in time to Jablonna, and in the evening bring them back to Warsaw. So that is how I ended up listening to all lectures and discussions and more.

Fig. 1 The Staszica Palace in Warsaw

Fig. 2 Professor J. Synge delivering the opening lecture

followed by a short discussion, the session was adjourned and all participants were transferred to Jablonna.

Jablonna is a small town about 20 km from Warsaw. In XVIII century a famous Polish aristocratic family of Poniatowski built there a summer palace and two adjacent buildings with several rooms for their guests and servants. The Palace was surrounded

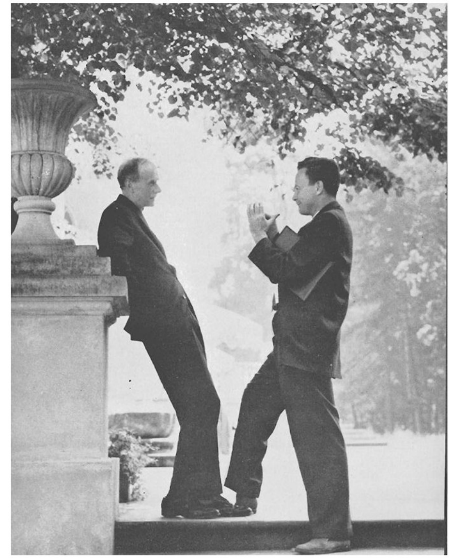

Fig. 6 Paul Dirac and Richard Feynman at Jablonna

the 2nd World War such a large group of physicists from the West and the East were able to meet. There were continuous discussions, usually in small groups between scientists coming from the West and the East. Also Germans from the DDR and the Bundes Republik were able to meet for the first time since the construction of the Berlin wall. It was a conference attended by many outstanding scientists. All leading physicists working at that time on general relativity and gravitation were present in Jablonna, including P. A. M. Dirac, R. Feynman, J. A. Wheeler, P. G. Bergmann, H. Bondi, S. Chandrasekhar, B. DeWitt, V. Ginzburg, D. Ivanenko, A. Lichnerowicz, C. Moller, L. Rosenfeld and J. Weber among others. One can say that Jablonna was a nesting place of Nobel Prize winners—Paul Dirac, Richard Feynman, Subrahmanyan Chandrasekhar, Vitali Ginzburg and also Peter Higgs were there. The main topics of discussions in Jablonna concentrated on general properties of gravitational radiation, quantization of gravity and exact solutions of the Einstein field equations. Only one talk given by Vitali Ginzburg was devoted to observational tests of general relativity (Figs. 6, 7, 8).

The most memorable lecture, in a dynamic showman style, was delivered by Richard Feynman. He presented his program of quantizing general relativity modeled on his very successful approach to quantum electrodynamics. Of course, he used Feynman diagrams. I am sure that Abhay Ashtekar will tell you more about it. After the conference I have listened to Feynman's talk many times trying to transcribe it from tapes. Fortunately John Stachel stayed in Warsaw for several months after the conference

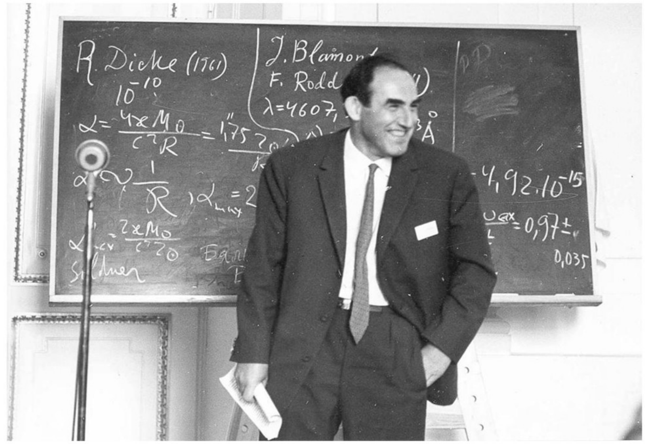

Fig. 7 Vitali Ginzburg delivering his lecture at the Jablonna conference

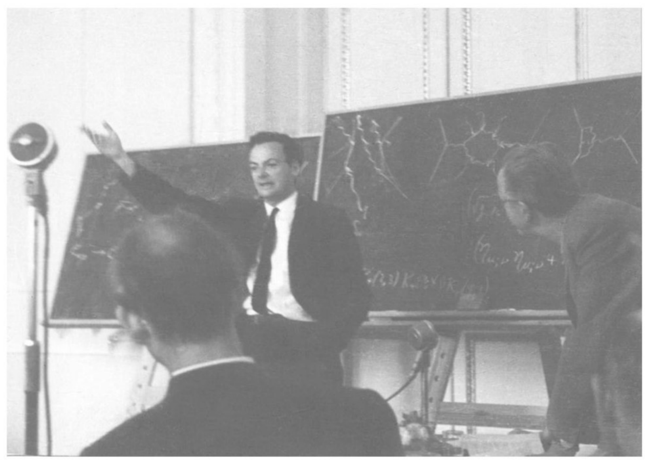

Fig. 8 Richard Feynman delivering his lecture at the Jablonna conference

"Incidentally, to give you some idea of the difference in order to calculate this diagram Fig. 4b the Young-Mills case took me about a day; to calculate the diagram in the case of gravitation I tried again and again and was never able to do it; and it was finally put on a computing machine—I don't mean the arithmetic, I mean the algebra of all the terms coming in, just the algebra; I did the integrals myself later, but the algebra of the thing was done on a machine by John Matthews so I couldn't done it by hand. In fact, I think it's historically interesting that it's the first problem in algebra that I know of that was done on a machine that has not been done by hand." Just for

A. Einstein (1930) about J. Kepler (1571-1630)

Precisely in such a troubled and turbulent time as ours, when it is hard to summon up joy about mankind and the progress of human affairs, it is especially comforting to think of such a great and serene person as Kepler. He lived at a time when the very conception of universal lawfulness of nature was not at all established. How great must have been his faith in such lawfulness, to have the strength to endure decades of patient, difficult work—supported by no one and understood by few—in the empirical investigation of planetary movement and its lawful mathematical expression!

Our admiration for this wonderful man is joined with another feeling of admiration and veneration, not for any person, but for the mysterious harmony of Nature into which we were born.

Johannes Kepler lived a very hard life in very difficult times (it was the Thirty Years War in Europe)

Ioannis Keppleri

HARMONICES
MVNDI

LIBRI V. QVORVM

Primus GEOMETRICVS, De Figurarum Regularium, quæ Proportiones Harmonicas conſtituunt, ortu & demonſtrationibus.
Secundus ARCHITECTONICVS; ſeu ex GEOMETRIA FIGVRATA, De Figurarum Regularium Congruentia in plano vel ſolido:
Tertius propriè HARMONICVS, De Proportionum Harmonicarum ortu ex Figuris; deque Naturâ & Differentiis rerum ad cantum pertinentium, contra Veteres:
Quartus METAPHYSICVS, PSYCHOLOGICVS & ASTROLOGICVS, De Harmoniarum mentali Eſſentiâ earumque generibus in Mundo; præſertim de Harmonia radiorum, ex corporibus cœleſtibus in Terram deſcendentibus, eiuſque effectu in Natura ſeu Anima ſublunari & Humana:
Quintus ASTRONOMICVS & METAPHYSICVS, De Harmoniis abſolutiſſimis motuum cœleſtium, ortuque Eccentricitatum ex proportionibus Harmonicis.
Appendix habet comparationem huius Operis cum Harmonices Cl. Ptolemæi libro III. cumque Roberti de Fluctibus, dicti Flud. Medici Oxonienſis ſpeculationibus Harmonicis, operi de Macrocoſmo & Microcoſmo inſertis.

Cum S. C. Mtis. Priuilegio ad annos XV.

Lincii Auſtriæ,
Sumptibus GODOFREDI TAMPACHII Bibl. Francof.
Excudebat IOANNES PLANCVS.

ANNO M. DC. XIX.

THE FIVE BOOKS OF
Johannes Kepler's
HARMONY OF THE WORLD
of which

The first is GEOMETRICAL, on the origin and constructions of the regular figures which establish the harmonic proportions;
The second is ARCHITECTONIC, or comes from the GEOMETRY OF FIGURES, on the congruence of the regular figures in the plane or solid;
The third is specifically HARMONIC, on the origin of the harmonic proportions in the figures, and on the nature and distinguishing features of matters relating to music, contrary to the ancients;
The fourth is METAPHYSICAL, PSYCHOLOGICAL, AND ASTROLOGICAL, on the mental essence of the harmonies and on the types of them in the world, especially on the harmony of the rays which descend from the heavenly bodies to the Earth, and on its effect on Nature or the sublunary and human soul;
The fifth is ASTRONOMICAL AND METAPHYSICAL, on the most perfect harmonies of the celestial motions, and the origin of the eccentricities in the harmonic proportions.
The Appendix contains a comparison of this work with Book III of the *Harmony* of Claudius Ptolemy and with the harmonic speculations of Robert of the Floods, called Fludd, the Oxford physician, inserted in his work on the macrocosm and microcosm.

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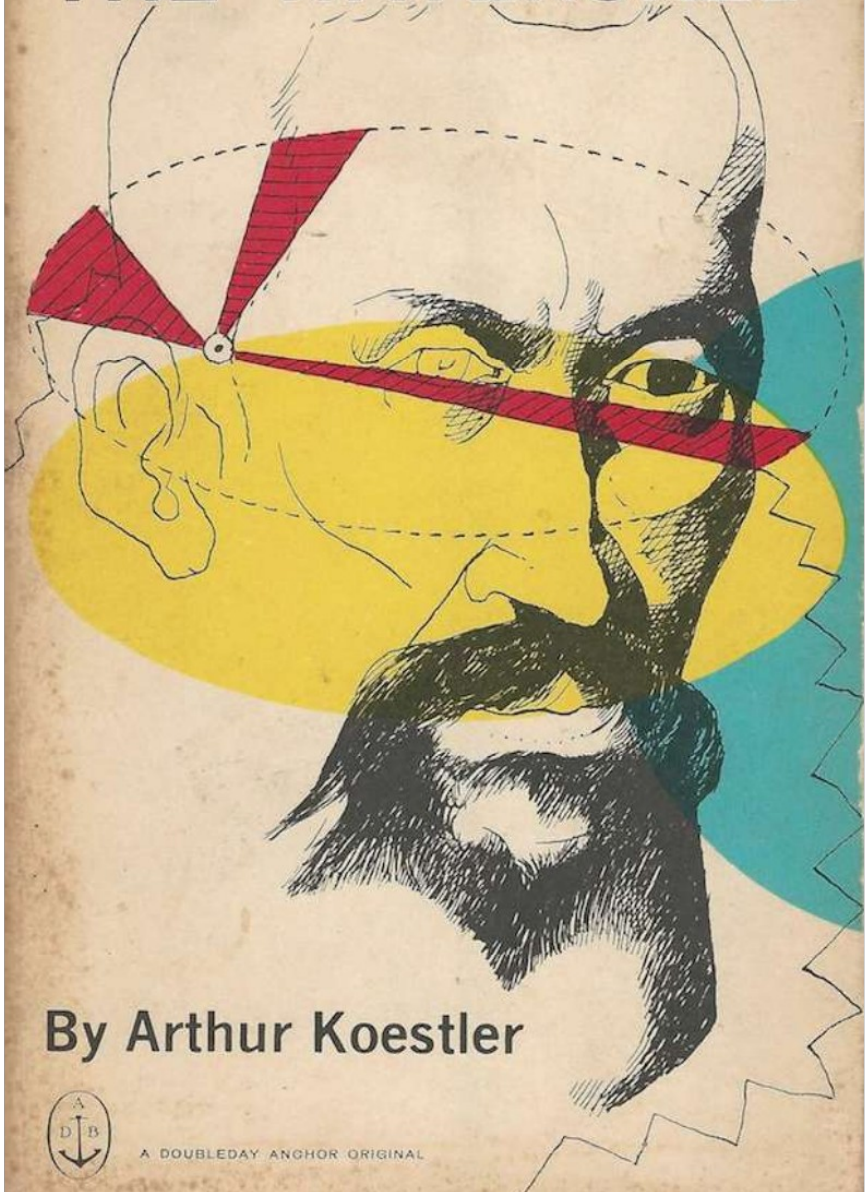

By Arthur Koestler

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ИЗ ИСТОРИИ ФИЗИКИ

531.352 (09)

ИОГАНН КЕПЛЕР: ОТ «МИСТЕРИИ» ДО «ГАРМОНИИ»

Ю. А. Данилов, Я. А. Смородинский

Though this be madness, yet there is method in't *)
(«Hamlet», act II, sc. ii)

'Αναρμονικὸς μὴ κρινέτω **)
(надпись на экземпляре «Гармонии мира», принадлежавшем биографу Кеплера Максу Каспару)

На одной из страниц книжного каталога, который был издан к весенней Франкфуртской ярмарке 1597 г. (в крупнейшем центре торговли книгами в то время), появилось новое странно звучащее имя Repleus. Под невольным псевдонимом, обязанным лишь небрежности наборщика, скрывалось совсем другое, также мало кому известное имя Иоганна Кеплера.

Маленькая книжка, отпечатанная незадолго до ярмарки (в конце 1596 г.), носила вычурное название «Предвестник космографических исследований, содержащий тайну мироздания относительно чудесных пропорций между небесными кругами и истинных причин числа и размеров небесных сфер, а также периодических движений, изложенный с помощью пяти правильных тел Иоганном Кеплером из Вюртемберга, математиком достославной провинции Штирии» ***).

Если не считать календарей, составление которых входило в обязанности математика провинции, «Предвестник», или, как предпочитал называть его сам Кеплер, «Misterium Cosmographicum» («Тайна мироздания»), был первым сочинением Кеплера на астрономические темы и единственным из его трудов, выдержавшим два прижизненных издания. Уступая настояниям друзей, Кеплер на склоне лет предпринял второе издание «для пользы не только книготорговцев, но и ученых». Обращаясь к новому читателю, Кеплер уже в конце своего жизненного пути (оставались еще ненаписанными только «Рудольфовы таблицы») с гордостью писал в посвящении:

«Прошло почти 25 лет с тех пор, как я выпустил в свет небольшую книжку «Тайна мироздания». И хотя в то время я был еще очень молод и эта публикация была моей первой астрономической работой, все же успех, сопутствовавший ей в последующие

*) Пусть это безумие, но в нем есть система.—«Гамлет», акт. 2, сц. 2. («Гамлет» издан в год встречи Кеплера с Тихо Браге.)
**) В ком нет музыки, да молчит.
***) Все переводы с латыни отрывков из сочинений Кеплера и пояснения к переводам [в квадратных скобках] сделаны авторами статьи.

The founders of GR studies in Russia

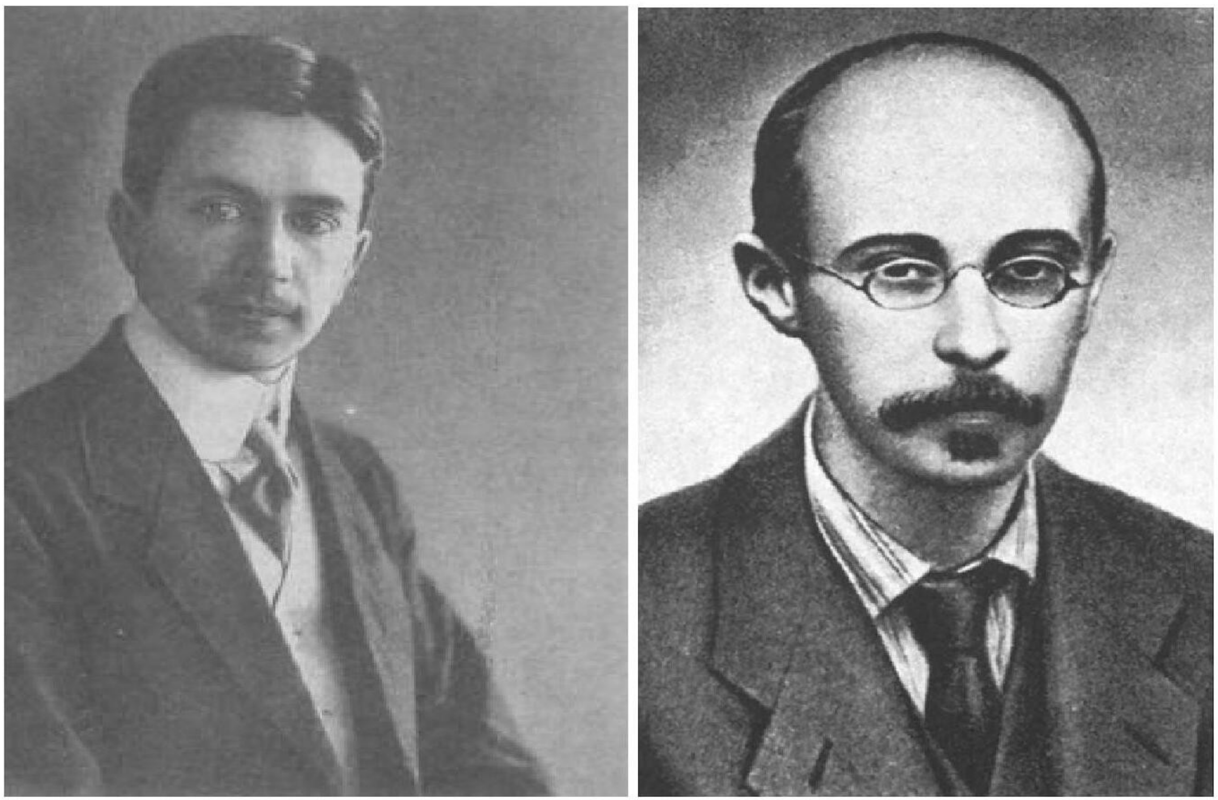

Figure 1. V. K. Frederiks who was a founder of Russian schools in GR and theory of liquid crystals (left) and Alexander Friedmann who was the founde of physical cosmology(right).

Vsevolod Konstantinovich Frederiks 13.04.1885 (Warsaw) – 06.01.1944 (?) (Gorky ?)

In 1903 VKF finished gymnasium in Nizhnij Novgorod

In 1907 VKF finished Geneve University with specialisation in physics

In 1909 VKF got PhD in physics under supervision G. E. Guye (Geneve)

In 1911 VKF an assistant at the Theoretical division of Physics Institute at Gottingen under W. Voigt

In 1914 civil prisoner, private assistant of D. Hilbert

Woldemar Voigt (1850-1919) was the Frederiks supervisor at Institute of Physics in Gottingen University

Nachrichten

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und der

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zu Göttingen.

10. März. **№ 2.** 1887.

Königliche Gesellschaft der Wissenschaften.

Sitzung vom 8. Januar.

Ueber das Doppler'sche Princip.

Von

W. Voigt.

Die Differentialgleichungen für die Oscillationen eines elastischen incompressibeln Mediums sind bekanntlich:

$$\frac{\partial^2 u}{\partial t^2} = \omega^2 \Delta u$$
$$\frac{\partial^2 v}{\partial t^2} = \omega^2 \Delta v \qquad 1)$$
$$\frac{\partial^2 w}{\partial t^2} = \omega^2 \Delta w$$

worin ω die Fortpflanzungsgeschwindigkeit der Oscillationen — genauer die Fortpflanzungsgeschwindigkeit ebener Wellen mit constanter Amplitude — bezeichnet. Dabei ist vorausgesetzt, daß u, v, w die Relation erfüllen:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0. \qquad 1')$$

Es seien nun $u = U$, $v = V$, $w = W$ Lösungen dieser Gleichungen, welche an einer gegebenen Oberfläche $f(\bar{x}, \bar{y}, \bar{z}) = 0$ gegebene von der Zeit abhängige Werthe $\bar{U}$, $\bar{V}$, $\bar{W}$ annehmen, so kann man sagen, daß diese Functionen U, V, W das Gesetz darstellen, nach welchem die Oberfläche $f = 0$ leuchtet.

In 1918 VKF came back in Moscow, work in Institute of Physics and Biophysics

In 1919 VKF was a senior physicist at State Optical Institute, a member of Atomic commission, associate professor in Petrograd State University, professor in Pedagogical Institute

In 1920 VFK is a lecturer at Polytechnic Institute

In 1921 VKF published the first review on GR in Soviet Physics Uspekhi

In 1923 VKF was a senior physicist in Institute of Physics and Technology

In 1924 VKF and AAF published of the first chapter of their joint book “Basics of GR”

In 1926 VKF was a Consultant to the Geological Committee

In Autumn 1927 VKF married Maria Dmitrievna Shostakovich (a sister of composer D. D. Shostakovich).

In 1931 VKF was Head of the Crystallization Laboratory in LPTI

In 1933 VKF was Head of anisotropic liquid Laboratory in LPTI

In 1934 VKF got Dsc degree without a formal defense, nominated by the LPTI Scientific Council as a candidate for corresponding member of Soviet Academy of Science, co-editor with A. P. Afanasiev of Course on General Physics (I. K. Kikoin, Yu. B. Khariton were among authors of chapters in the book)

On October 20, 1936 VKF was arrested as a defendant in the Pulkovo case.

On May 23, 1937 VKF sentenced to 10 years in prison camps (Taishetlag)

In 1939   VKF was in Orel prison

In 1940   VKF was in Ukhta (Izhemlag, Komi)

On January 6, 1944 VKF died. Only in 1957 relatives got an official document on his death, where is the dash made in the place of death

Alexander Alexandrovich Friedmann (Friedman)
4(16).06.1888 (Sankt-Peterburg) – 16.09.1925 (Leningrad)

In 1897 - 1906 AAF was a student at the Second SPB gymnasium

In 1905 AAF wrote the first mathematical paper (published in 1907)

In 1906 - 1910 AAF was student at mathematical division of the faculty of physics and mathematics

In 1910 - 1913 AAF left in SPB University for a preparation for a professor position

In 1913 AAF passed master exams and got master degree

In 1914 – 1916 AAF joined the army as a volunteer, he served in aviation units

In 1918 – 1920 AAF was a professor of mechanics deprartment of Perm University

In 1920 – 1924 AAF was a researcher at Atomic Commission in State Optical Institute

In 1920 – 1924 AAF was a professor at the Faculty of Physics and Mechanics of Petrograd Polytechnic Institute

In 1920 – 1925 AAF was a senior physicist, head of mathematical bureau, scientific secretary and since February 1925 director of Main Geophysical Observatory

In 1922 AAF published his first cosmological paper

In 1923 AAF published his book “World as space and time”

In 1923 AAF travelled to Germany and Norge

In 1923 AAF wrote a letter to A. Einstein

In 1924 AAF published his second cosmological paper

In 1924 AAF (with V. K. Frederics) published «Foundations of relativity theory»

In July 1925 AAF and P. F. Fedoseenko made a record-breaking balloon ascent (flight at 7400 m)

In July – August 1925 AAF and his wife relaxed at the Crimea cost

On August 17, 1925 AAF came back to Leningrad, while his wife (N. E. Malinina) went to another town.

Perhaps, in his last train trip AAF was infected by a typhus since he ate dirty fruits. According to Friedman himself, he probably got infected by eating an unwashed pear bought at one of the railway stations on the way from Crimea to Leningrad. Suddenly (on September 2) he felt sick.

On September 16, 1925 AAF died in hospital.

He was buried at the Smolensk Orthodox Cemetery in Leningrad.


ФРИДМАН
АЛЕКСАНДР
АЛЕКСАНДРОВИЧ
1888 — 1925
Выдающийся ученый, создатель
теории нестационарной Вселенной.
Выпускник Второй Санкт-Петербургской
гимназии.
БЛАГОДАРНЫЕ ПОТОМКИ

The revolutionary breakthrough in 1917

Assuming uniform and isotropic distribution of matter in the Universe A. Einstein found the first (static) cosmological solution.

Remarkably, so rough approximation for matter distribution give an opportunity to describe a behaviour of the Universe.

Later it was found that this (static) solution is unstable.

Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie.

Von A. Einstein.

Es ist wohlbekannt, daß die Poissonsche Differentialgleichung

$$\Delta\phi = 4\pi K\rho \tag{1}$$

in Verbindung mit der Bewegungsgleichung des materiellen Punktes die Newtonsche Fernwirkungstheorie noch nicht vollständig ersetzt. Es muß noch die Bedingung hinzutreten, daß im räumlich Unendlichen das Potential ϕ einem festen Grenzwerte zustrebt. Analog verhält es sich bei der Gravitationstheorie der allgemeinen Relativität; auch hier müssen zu den Differentialgleichungen Grenzbedingungen hinzutreten für das räumlich Unendliche, falls man die Welt wirklich als räumlich unendlich ausgedehnt anzusehen hat.

Bei der Behandlung des Planetenproblems habe ich diese Grenzbedingungen in Gestalt folgender Annahme gewählt: Es ist möglich, ein Bezugssystem so zu wählen, daß sämtliche Gravitationspotentiale $g_{\mu\nu}$ im räumlich Unendlichen konstant werden. Es ist aber a priori durchaus nicht evident, daß man dieselben Grenzbedingungen ansetzen darf, wenn man größere Partien der Körperwelt ins Auge fassen will. Im folgenden sollen die Überlegungen angegeben werden, welche ich bisher über diese prinzipiell wichtige Frage angestellt habe.

§ 1. Die Newtonsche Theorie.

Es ist wohlbekannt, daß die Newtonsche Grenzbedingung des konstanten Limes für ϕ im räumlich Unendlichen zu der Auffassung hinführt, daß die Dichte der Materie im Unendlichen zu null wird. Wir denken uns nämlich, es lasse sich ein Ort im Weltraum finden, um den herum das Gravitationsfeld der Materie, im großen betrachtet, Kugelsymmetrie besitzt (Mittelpunkt). Dann folgt aus der Poissonschen Gleichung, daß die mittlere Dichte ρ rascher als $\frac{1}{r^2}$ mit wachsender Entfernung r vom Mittelpunkt zu null herabsinken muß, damit ϕ im

Über die Krümmung des Raumes.

Von **A. Friedman** in Petersburg.

Mit einer Abbildung. (Eingegangen am 29. Juni 1922.)

§ 1. 1. In ihren bekannten Arbeiten über allgemeine kosmologische Fragen kommen Einstein[1]) und de Sitter[2]) zu zwei möglichen Typen des Weltalls; Einstein erhält die sogenannte Zylinderwelt, in der der Raum[3]) konstante, von der Zeit unabhängige Krümmung besitzt, wobei der Krümmungsradius verbunden ist mit der Gesamtmasse der im Raume vorhandenen Materie; de Sitter erhält eine Kugelwelt, in welcher nicht nur der Raum, sondern auch die Welt in gewissem Sinne als Welt konstanter Krümmung angesprochen werden kann[4]). Dabei werden wie von Einstein so auch von de Sitter gewisse Voraussetzungen über den Materietensor gemacht, die der Inkohärenz der Materie und ihrer relativen Ruhe entsprechen, d. h. die Geschwindigkeit der Materie wird als genügend klein vorausgesetzt im Vergleich zu der Grundgeschwindigkeit[5]) — der Lichtgeschwindigkeit.

Das Ziel dieser Notiz ist, erstens die Ableitung der Zylinder- und Kugelwelt (als spezielle Fälle) aus einigen allgemeinen Annahmen, und zweitens der Beweis der Möglichkeit einer Welt, deren Raumkrümmung konstant ist in bezug auf drei Koordinaten, die als Raumkoordinaten gelten, und abhängig von der Zeit, d. h. von der vierten — der Zeitkoordinate; dieser neue Typus ist, was seine übrigen Eigenschaften anbetrifft, ein Analogon der Einsteinschen Zylinderwelt.

2. Die Annahmen, die wir unseren Betrachtungen zugrunde legen, zerfallen in zwei Klassen. Zu der ersten Klasse gehören Annahmen, welche mit den Annahmen Einsteins und de Sitters zusammen-

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[1]) Einstein, Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie, Sitzungsberichte Berl. Akad. 1917.

[2]) de Sitter, On Einstein's theory of gravitation and its astronomical consequences. Monthly Notices of the R. Astronom. Soc. 1916—1917.

[3]) Unter „Raum" verstehen wir hier einen Raum, der durch eine Mannigfaltigkeit von drei Dimensionen beschrieben wird; der „Welt" entspricht eine Mannigfaltigkeit von vier Dimensionen.

[4]) Klein, Über die Integralform der Erhaltungssätze und die Theorie der räumlich-geschlossenen Welt. Götting. Nachr. 1918.

[5]) Siehe diesen Namen bei Eddington in seinem Buche: Espace, Temps et Gravitation, 2 Partie, S. 10. Paris 1921.

Bemerkung zu der Arbeit von A. Friedmann[1]) „Über die Krümmung des Raumes".

Von A. Einstein in Berlin.

(Eingegangen am 18. September 1922.)

Die in der zitierten Arbeit enthaltenen Resultate bezüglich einer nichtstationären Welt schienen mir verdächtig. In der Tat zeigt sich, daß jene gegebene Lösung mit den Feldgleichungen (A) nicht verträglich ist. Aus jenen Feldgleichungen folgt nämlich bekanntlich, daß die Divergenz des Tensors T_{ik} der Materie verschwindet. Im Falle des durch (C) und (D_3) charakterisierten Ansatzes führt dies auf die Beziehung

$$\frac{\partial \varrho}{\partial x_4} = 0,$$

welche zusammen mit (8) die zeitliche Konstanz des Weltradius R erfordert. Die Bedeutung der Arbeit besteht also gerade darin, daß sie diese Konstanz beweist.

Berlin, September 1922.

[1]) ZS. f. Phys. **10**, 377—386, 1922.

Notiz zu der Arbeit von A. Friedmann „Über die Krümmung des Raumes".

Von **A. Einstein** in Berlin.

(Eingegangen am 31. Mai 1923.)

Ich habe in einer früheren Notiz [1]) an der genannten Arbeit [2]) Kritik geübt. Mein Einwand beruhte aber — wie ich mich auf Anregung des Herrn Krutkoff an Hand eines Briefes von Herrn Friedmann überzeugt habe — auf einem Rechenfehler. Ich halte Herrn Friedmanns Resultate für richtig und aufklärend. Es zeigt sich, daß die Feldgleichungen neben den statischen dynamische (d. h. mit der Zeitkoordinate veränderliche) zentrisch-symmetrische Lösungen für die Raumstruktur zulassen.

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[1]) ZS. f. Phys. **11**, 326, 1922.
[2]) Ebenda **10**, 377, 1922.

1963 г. Июль *Т. LXXX, вып. 3*

УСПЕХИ ФИЗИЧЕСКИХ НАУК

ЗАМЕЧАНИЕ К РАБОТЕ А. ФРИДМАНА «О КРИВИЗНЕ ПРОСТРАНСТВА»*)

А. Эйнштейн

Результаты относительно нестационарного мира, содержащиеся в упомянутой работе, представляются мне подозрительными. В действительности оказывается, что указанное в ней решение не удовлетворяет уравнениям поля (A). Как известно, из этих уравнений следует, что дивергенция тензора вещества T_{ik} обращается в нуль. В случае, характеризуемом предположениями (C) и (D_3), это приводит к соотношению

$$\frac{\partial \varrho}{\partial x_4} = 0,$$

что вместе с уравнением (8) требует постоянства радиуса мира во времени. Следовательно, значение этой работы в том и состоит, что она доказывает это постоянство.

УСПЕХИ ФИЗИЧЕСКИХ НАУК

К РАБОТЕ А. ФРИДМАНА «О КРИВИЗНЕ ПРОСТРАНСТВА»**)

А. Эйнштейн

В предыдущей заметке я подверг критике названную выше работу. Однако моя критика, как я убедился из письма Фридмана, сообщенного мне г-ном Крутковым, основывалась на ошибке в вычислениях. Я считаю результаты г. Фридмана правильными и проливающими новый свет. Оказывается, что уравнения поля допускают наряду со статическими также и динамические (т. е. переменные относительно времени) центрально-симметричные решения для структуры пространства.

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*) A. Einstein, Bemerkung zu der Arbeit von A. Friedman «Über die Krümmung des Raumes», Zs. Phys. 11, 326 (1922).

**) A. Einstein, Notiz zu der Arbeit von A. Friedman «Über die Krümmung des Raumes», Zs. Phys. 21, 228 (1923).

Имя Фридмана до сих пор было в незаслуженном забвении. Это несправедливо и это необходимо исправить. Мы должны увековечить это имя. Ведь Фридман — один из пионеров советской физики, ученый, внесший большой вклад в отечественную и мировую науку. Надо опубликовать собрание всех его трудов и издать его биографию.

ЗАМЕЧАНИЕ К РАБОТЕ А. ФРИДМАНА «О КРИВИЗНЕ ПРОСТРАНСТВА»[64]

А. Эйнштейн

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$$\frac{\partial \rho}{\partial x_4} = 0,$$

что вместе с уравнением (8) требует постоянства радиуса мира во времени. Следовательно, значение этой работы в том и состоит, что она доказывает это постоянство.

К РАБОТЕ А. ФРИДМАНА «О КРИВИЗНЕ ПРОСТРАНСТВА»

А. Эйнштейн

В предыдущей заметке я подверг критике названную выше работу. Однако моя критика, как я убедился из письма Фридмана, сообщенного мне г-ном Крутковым, основывалась на ошибке в вычислениях. Я считаю результаты г. Фридмана правильными и проливающими новый свет. Оказывается, что уравнения поля допускают наряду со статическими также и динамические (т. е. переменные относительно времени) центрально-симметричные решения для структуры пространства.

РАБОТЫ А. А. ФРИДМАНА ПО ТЕОРИИ ТЯГОТЕНИЯ ЭЙНШТЕЙНА[65]

В. А. Фок

Среди научных работ А. А. Фридмана его исследования по теории тяготения Эйнштейна составляют по своему числу лишь небольшую долю (менее одной десятой части) всех опубликованных им работ, но по тому вли-

3. Friedman's Letter to Einstein[3]

Petrograd
Central Observatory,
Vasil'yevskiy Ostrov, Line 23, 2
Professor A. Friedmann

6 December 1922

Dear Esteemed Professor,

From a letter of a friend of mine, who is now staying abroad, I had the honor to learn that you had sent a short note to the 11th volume of *Zeitschrift für Physik*, in which you had pointed out that, if one adopted the assumptions (D_3) and (C) of my article "On the Curvature of Space,"[4] then the world equations you derived would entail that the radius of curvature of the universe should be a constant value that does not depend on time. You have obtained this result based on the fact that the vanishing of the divergence of the tensor T_{ik} is a necessary consequence of the world equations.

From this vanishing of the divergence of the tensor T_{ik} you have inferred the relation

$$(*) \qquad \frac{\partial \rho}{\partial x_4} = 0.$$

Such a relation means, naturally, that the radius of curvature R is constant and, hence, that the calculations in my work are in error.

However, I could not derive the relation (*) from the condition that the divergence of the tensor T_{ik} vanishes; the result I obtained is *consistent*[5] with the possibility of a non-stationary world. Given that such a possibility

The calculations have shown that, in this case, there can exist both a world with a constant (now negative) curvature and a world with a changing (in time) curvature.

The possibility[8] of obtaining a world with a constant negative curvature from your equations is of exceptional interest to me. This is why I am asking you not to delay your reply to this letter of mine, though I am aware that you are very busy.

If you find my calculations correct, I kindly request that you inform the editors of *Zeitschrift für Physik* about it. Perhaps in this case you will publish a correction to your earlier statement or provide an opportunity for a portion of this letter to be published.

Respectfully Yours,
A. Friedmann

4. A Brief Chronological Commentary to Friedmann's Letter

"A friend of mine who is now staying abroad" was Yuri Krutkov, Friedmann's associate at the Petrograd Polytechnical Institute. In 1922–23 he was on a business trip abroad, working in Berlin, Göttingen, and Leiden. In Leiden he was hosted by the University's department of theoretical physics, which (after Lorentz) was headed by Paul Ehrenfest.

One of the first Russian theoretical physicists, Krutkov, along with Friedmann and a few other young physicists and mathematicians, participated in a seminar that gathered around Ehrenfest in pre-revolutionary Petersburg in 1907–1912. Ehrenfest, whose wife was Russian, was fluent sorry if that phrase had been left in the note. It seems that it was precisely Krutkov who had saved him from that mistake.

We conclude with a chronological summary of important events described above:

- Friedmann's article (Friedmann 1922) was received by the editor of *Zeitschrift für Physik* on 29 June 1922.
- Einstein's first note (Einstein 1922) was received by the editor on 18 September 1922.
- Friedmann's letter to Einstein was sent on 6 December 1922.
- Krutkov's meetings with Einstein in Leiden took place on 7–18 May 1923.
- Einstein's second note (Einstein 1923) was received by the editor on 21 May 1923.

Über die Möglichkeit einer Welt mit konstanter negativer Krümmung des Raumes.

Von **A. Friedmann** in Petersburg.

(Eingegangen am 7. Januar 1924.)

§ 1. 1. In unserer Notiz „Über die Krümmung des Raumes“ [1]) haben wir diejenigen Lösungen der Einsteinschen Weltgleichungen betrachtet, welche zu Welttypen führen, denen eine konstante positive Krümmung als gemeinsames Merkmal angehört; dabei haben wir alle möglichen Fälle erörtert. Die Möglichkeit, aus den Weltgleichungen eine Welt konstanter positiver räumlicher Krümmung abzuleiten, steht aber mit der Frage nach der Endlichkeit des Raumes im Zusammenhange. Aus diesem Grunde dürfte es von Interesse sein zu untersuchen, ob man aus denselben Weltgleichungen eine Welt konstanter negativer Krümmung erhalten kann, von deren Endlichkeit (auch unter einigen ergänzenden Annahmen) wohl kaum die Rede sein kann.

In der vorliegenden Notiz wird gezeigt, daß es wirklich möglich ist, aus den Einsteinschen Weltgleichungen eine Welt mit konstanter negativer Krümmung des Raumes abzuleiten. Wie in der zitierten Arbeit, so haben wir auch hier zwei Fälle zu unterscheiden, nämlich 1. den Fall einer stationären Welt, deren Krümmung zeitlich konstant ist, und 2. den Fall einer nichtstationären Welt, deren Krümmung zwar räumlich konstant ist, wohl aber im Laufe der Zeit variiert. Zwischen den stationären Welten konstanter negativer und denjenigen konstanter positiver räumlicher Krümmung besteht ein wesentlicher Unterschied. Die Welten stationärer negativer Krümmung lassen nämlich keine positive Dichte der Materie zu; dieselbe ist entweder Null oder negativ. Die physikalisch möglichen stationären Welten (d. h. diejenigen mit nicht negativer Dichte der Materie) finden demzufolge ihr Analogon in der de Sitterschen, nicht aber in der Einsteinschen Welt [2]).

Zum Schluß dieser Notiz werden wir die Frage berühren, ob man überhaupt auf Grund der Krümmung des Raumes über dessen Endlichkeit oder Unendlichkeit urteilen darf.

2. Wir wenden uns zu unseren allgemeinen Annahmen, die wir in dieselben zwei Klassen wie in der zitierten Notiz gruppiert denken;

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[1]) ZS. f. Phys. **10**, 377, 1922, Heft 6.

[2]) Auf die Notwendigkeit einer besonderen Untersuchung über die Möglichkeit einer Welt mit negativem Krümmungsmaße des Raumes hat mich mein Freund Prof. Dr. Tamarkine aufmerksam gemacht.

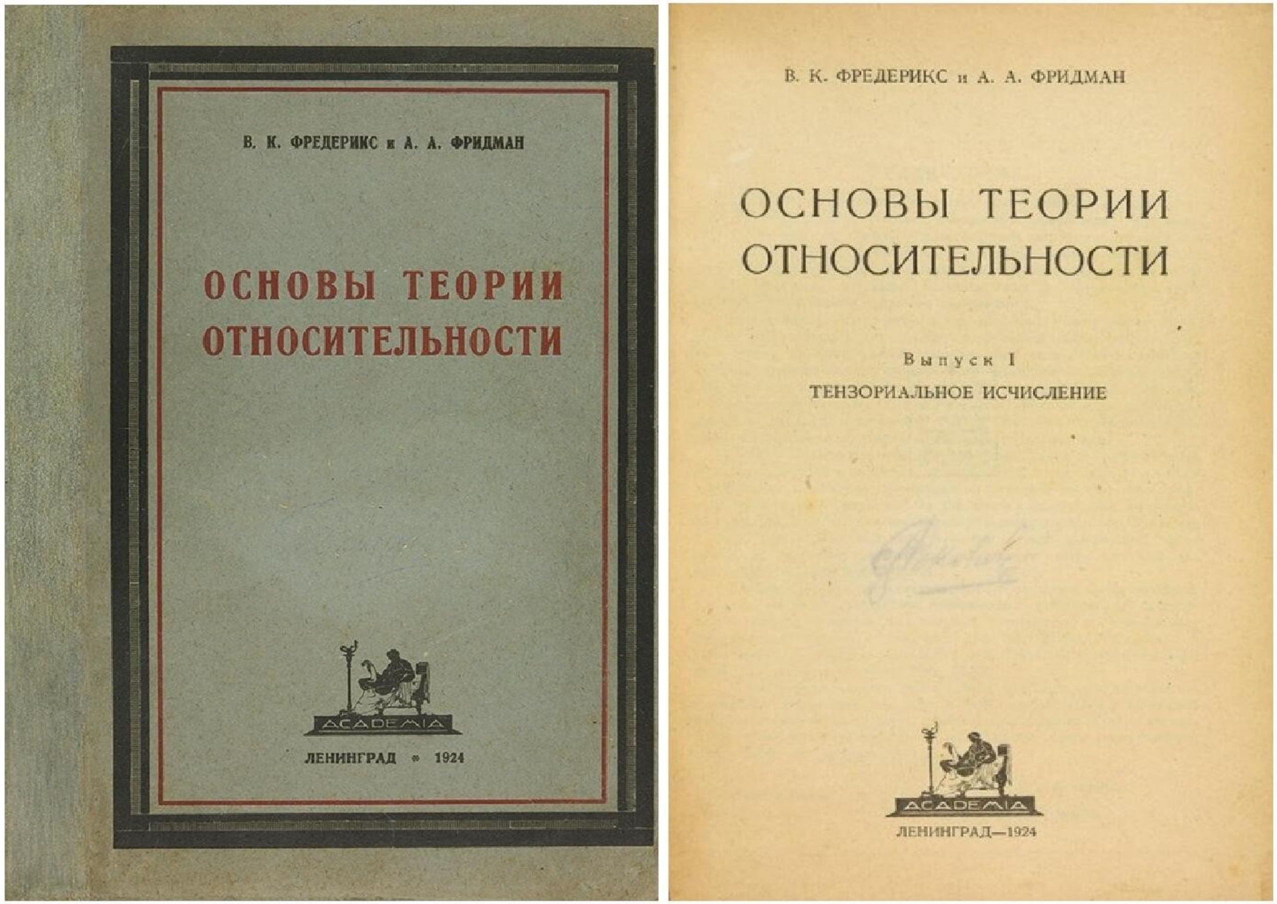


Figure 2. Cover page (left) of joint book "Basics of General Relativity" by V. K. Frederiks and A. A. Friedmann and its first page (right).

In 1933 at Caltech after the Lemaitre’s lecture A. Einstein said: “This is the most beautiful and satisfactory explanation of creation to which I have ever listened”. This Einstein’s opinion was widely distributed through mass media. These circumstances had a negative impact on the development of cosmological studies in USSR for around thirty years.

Abbe Georges Henri Joseph Édouard Lemaître 7 July 1894 – 20 June 1966 (The Big Bang Father)

GL signed on voluntarily on 9 August 1914 and entered in Belgium army

GL gained his doctorate this was his licence to teach, not a PhD in 1920

GL got travelship to visit UK and USA in 1923

GL visited Slipher in Arizona and Hubble at Mount Wilson in the summer of 1925

GL defended his PhD Thesis at MIT in 1927

In 1927 GL published a paper "On a homogeneous expanding universe of constant mass", appeared in the *Annals of the Scientific Society of Brussels*. In the paper derived the law (which was called later the Hubble law). This derivation was omitted in the English translation published in 1931

“In October 1927, Einstein participated at the 5th Solvay Congress in Brussels, where the main topic was quantum theory. Lemaitre was not invited to those discussions, but Louvain is only 20 km from the capital, so during a break in the closed sessions he caught Einstein’s attention, and the two took a stroll in the Parc Leopold. Einstein commented favourably on Lemaitre’s mathematical competence, although he rejected the notion of an expanding universe as an abomination. And it was Einstein who, at this encounter, directed Lemaitre’s attention to Friedman’s work. Lemaitre found this news unsettling, but his confidence in Slipher’s data compelled him to continue to work on expansion as the key to interpreting the data on “nebular velocities”.” (S. Mitton, A & G April 2017)

In 2011 Mario Livio learned that GL decided to omit the Hubble law derivation since the law was known as Hubble law obtained from observations

In 2018 IAU decided to name the Hubble law as Hubble – Lemaitre law

In 1931 GL published a paper where he introduced a hot Universe model

In 1946, Lemaitre's book *L'Hypothesis de l'Atome Primitif, Essai de Cosmologie*2) had described his ideas at greater length, paying more attention to concepts of the quantum world. Lemaitre predicted also a temperature a few K as relic.

In 1948, Ralph Alpher and Robert Herman published a value of 5 K for the temperature of the cosmic microwave background

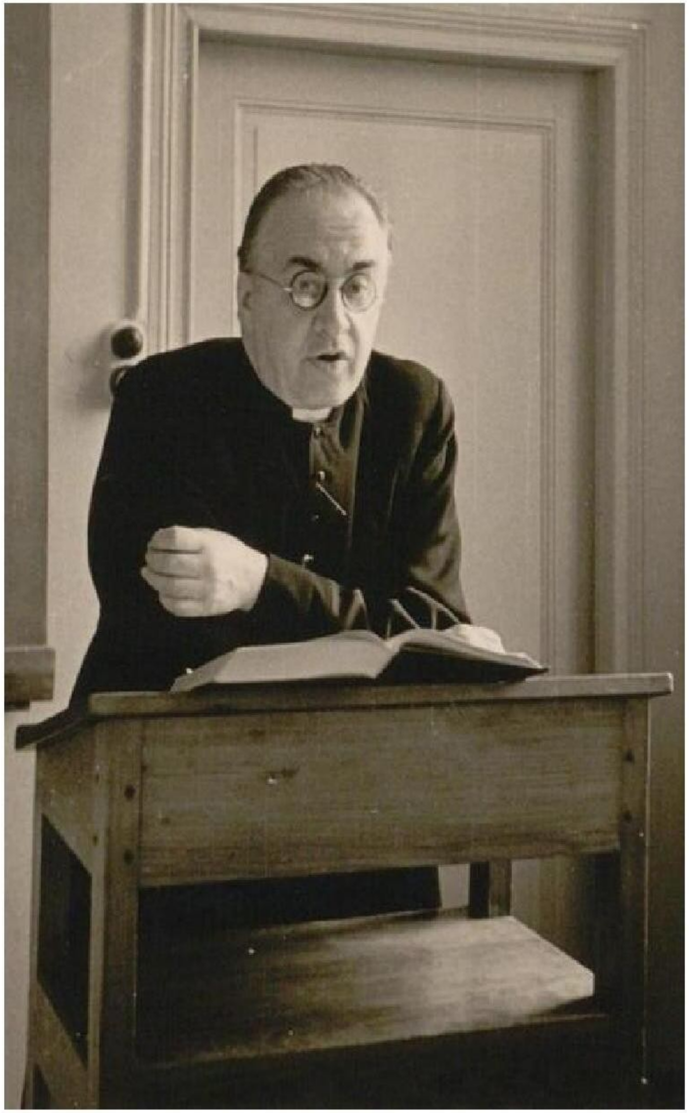


Figure 3. Abbé Georges Lemaitre who firstly discussed observational features of an Universe expansion and introduced a hot Universe model which was later called Big Bang.

Figure 65 Albert Einstein and Georges Lemaître at Pasadena in 1933 for the seminar on Hubble's observations and the Big Bang model of the universe.

However, even earlier M. Bronstein (Sov. Physics – Uspekhi, 1931) wrote in his review of cosmological models considered in the framework of GR “Friedman’s cosmological solutions are half forgotten”.

Чехов А. П. Записная книжка IV
A. P. Chekhov.

17. Национальной науки нет, как нет национальной таблицы умножения; что же национально, то уже не наука.

17. There is no national science, just as there is no national multiplication table; what is national is no longer science.

BSE (Second edition, v. 23, p. 109), Cosmology. As one can see, in contrast of other branches of physics Soviet atheistic philosophers were controlling cosmology in 1950s.

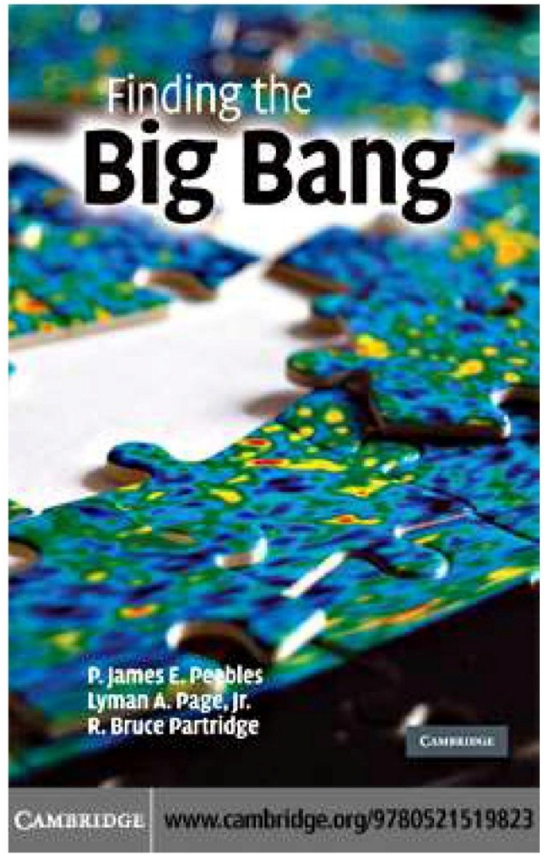
Современная буржуазная К. получила исчерпывающую философскую характеристику в словах А. А. Жданова: «Современная буржуазная наука снабжает поповщину, фидеизм новой аргументацией, которую необходимо беспощадно разоблачать. Взять хотя бы учение английского астронома Эддингтона о физических константах мира, которое прямёхонько приводит к пифагорейской мистике чисел... Не понимая диалектического хода познания, соотношения абсолютной и относительной истины, многие последователи Эйнштейна, перенося результаты исследования законов движения конечной, ограниченной области вселенной на всю бесконечную вселенную, договариваются до конечности мира, до ограниченности его во времени и пространстве, а астроном Милн даже „подсчитал", что мир создан 2 миллиарда лет тому назад. К этим английским учёным применимы, пожалуй, слова их великого соотечественника, философа Бэкона о том, что они обращают бессилие своей науки в клевету против природы» (Жданов А. А., Выступление на дискуссии по книге Г. Ф. Александрова «История западноевропейской философии» 24 июня 1947 г., 1952, стр. 42—43). Для современной буржуазной К. характерно перенесение на всю Вселенную свойств известной нам части Метагалактики, к тому же сильно схематизированных. Этим перенесением, при доплеровом истолковании красного смещения, и создаётся «теория расширяющейся Вселенной» (бельгийский физик аббат Ж. Леметр и др.). Сторонниками этой «теории» были, в частности, незаконно распространены на всю Вселенную найденные Фридманом решения уравнений тяготения Эйнштейна, включая уравнения с космич. постоянной (буржуазная релятивистская К.). Эта «теория» даёт различные варианты поведения Вселенной. Прошлое всей Вселенной она

In 1940s G. Gamow proposed the hot Universe model, calculated primodial nucleosynthesis and predicted an existence of CMB radiation. Gamow was the youngest corresponding member of Soviet Academy of Sciences (from 1932 to 1938, restored posthumously in 1990).

G. Gamow (on communications with Soviet Physicists)

So a couple of years ago ... You see, my situation with Russian scientists is that physicists and astronomers know that I am persona non grata, and they are afraid to write to me, and I don't want to write to them because I bring them into trouble. But biologists don't. A Russian name, well, there are many Russian names. So a couple of years ago I got from Luchnik some reprints. He was interested in this coding problem, and I sent him my reprints and letter. And this is my stationery, which probably you have seen.

https://www.aip.org/history-programs/niels-bohr-library/oral-histories/4325


Finding the
Big Bang
P. James E. Peebles
Lyman A. Page, Jr.
R. Bruce Partridge
CAMBRIDGE
CAMBRIDGE
www.cambridge.org/9780521519823

“Shmaonov described how, in the middle of the 1950s, he had been doing postgraduate research in the group of the well-known Soviet radio astronomers S. Khaikin and N. Kaidanovsky: he was measuring radio waves coming from space at a wavelength of 3.2 cm. Measurements were done with a horn antenna similar to that used many years later by Penzias and Wilson. Shmaonov carefully studied possible sources of noise. Of course, his instrument could not have been as sensitive as those with which the American astronomers worked in the 1960s. Results obtained by Shmaonov were reported in 1957 in his PhD Thesis and published in a paper (Shmaonov 1957) in the Soviet journal *Pribory i Tekhnika Eksperimenta* (*Instruments and Experimental Methods*)*. The conclusion of the measurements was: “The absolute effective temperature of radiation background ... appears to be 4 ± 3 K.” Shmaonov emphasized the independence of the intensity of radiation on direction and time.”

*Shmaonov, T., 1957, Method of absolute measurements of the effective temperature of radio emission with a low equivalent temperature [Методика абсолютных измерений эффективной температуры радиоизлучения с низкой эквивалентной температурой], *Pribori i Tekhnika Experimenta* (in Russia), 1, 83

Figure 4. Naum Lvovich Kaidanosky (left) and Semion Emmanuilovich Khaikin (right) who supervised T. A. Shmaonov at the Pulkovo Observatory in 1950s.

Shmaonov in 1957 in Pulkovo

*Аспирант Т. А. Шмаонов
в лаборатории Главной астрономической
обсерватории (1954 г.)*

*Радиотелескоп ГАО,
на котором работал
Т. А. Шмаонов*

Figure 5. Tigran Aramovich Shmaonov presents his talk about his discovery of CMB in 1957. The talk was delivered in the Institute for History of Natural Sciences and Technology in Moscow on 17 April 2017.

A typical version for an ignorance of the Shmaonov’s discovery

No one knew an astronomical sense of his discovery in 1950s (including S. E. Khaikin)

However, we have to keep in mind that dynamical models of Universe (Friedmann, Lemaitre, Gamow..) were banned due to Soviet Philosophy opinion on evolution of the Universe until June 1963 when this ban was lifted. In June 1963 Soviet Academy of Sciences changed its point of view on allowed models for the Universe evolution since it celebrated 75th anniversary since the Friedmann’s birthday. Therefore, we celebrated 60 years of Russian physical cosmology in 2023. Shmaonov (2021) wrote in the book on Khaikin: «Gamow’s works were not widely known in the world, in USSR his works were banned since he was considered an enemy of the people»

Kapitsa (1962) in “Experiment, theory, practice”: “ What has been said about physics can be applied to other areas of the natural sciences. The separation of theory from experiment, experience, and practice damages, first of all, the theory itself. I would like to say that the separation from experience and from life also occurred among philosophers who study the philosophical problems of natural science.

Here is another example that shows what insufficient understanding and knowledge of physical experiments leads to. Many still remember freshly how a number of philosophers, dogmatically applying the method of dialectics, proved the inconsistency of the theory of relativity. The greatest criticism from philosophers was subjected to the conclusion of the theory of relativity that energy is equivalent to mass multiplied by the square of the speed of light ($E = mc^2$). Physicists have long verified this law of Einstein in experiments with elementary particles. To understand these experiments, deep knowledge of modern physics was required, which some philosophers did not have. And so physicists carried out nuclear reactions and tested Einstein's law not on individual atoms, but on the scale of an atomic bomb. Physicists would be good if they followed the conclusions of some philosophers and stopped working on the problem of applying the theory of relativity to nuclear physics! In what position would physicists have put the country if they had not been prepared for the practical use of the achievements of nuclear physics?

This shows that the application of dialectics in the field of natural sciences requires an exceptionally deep knowledge of experimental facts and their theoretical generalization. Without this, dialectics itself cannot provide a solution to the problem. It is, so to speak, a Stradivarius violin, the most perfect of violins, but in order to play it, one must be a musician and know music. Without this, it will be as out of tune as an ordinary violin. ”

P. L. Kapitsa (1962, 1963) and Ya. B. Zeldovich (1963) played a great role to remove the ban on dynamical models for the Universe

P. L. Kapitsa (1963): “Friedmann made one of the most significant theoretical discoveries in astronomy—he predicted the expansion of the Universe. From Friedmann's solution of Einstein's cosmological equations, it followed that the radius of curvature of our world could change over time. A few years after Friedmann's work was published, the American astronomer Hubble discovered the recession of galaxies—a consequence of the expansion of the Universe*. Thus, Friedmann "at the tip of his pen" discovered an amazing phenomenon of cosmic scale...
Friedmann did not live to see his calculations confirmed by direct observation. But we now know that he was right. And we are obliged to give a fair assessment of the remarkable result of this scientist. Friedmann's name has been undeservedly forgotten until now. This is unfair and this needs to be corrected. We must perpetuate this name. After all, Friedmann is one of the pioneers of Soviet physics, a scientist who made a great contribution to domestic and world science. It is necessary to publish a collection of all his works and publish his biography.”

*Now it is called the Hubble – Lemaitre law.

Alexander Alexandrovich Friedman and Vsevolod Konstantinovich Fredericks, being professors at Petrograd (now Leningrad) University, were the first to introduce Russian physicists working in Petrograd to Einstein's recently created theory of gravity. It was at the very beginning of the twenties, when the blockade of Soviet Russia had just been broken and scientific literature began to arrive from abroad. A seminar was held at the university's Physics Institute, where, among others, reports on Einstein's theory were presented. The seminar participants were professors and senior students (there were few of them then). The main speakers on the theory of relativity were V. K. Fredericks and A. A. Friedman, but sometimes Y. A. Krutkov, V. R. Bursian and others spoke. I vividly remember the reports of Fredericks and Friedman. The style of these reports was different: Fredericks deeply understood the physical side of theory **), but did not like mathematical calculations, while Friedman focused not on physics, but on mathematics. He strove for mathematical rigor and attached great importance to a complete and accurate formulation of the initial assumptions. The discussions between Fredericks and Friedman were very interesting. (in Fok V A “The researches of A. A. Fridman on the Einstein theory of gravitation” Sov. Phys. Usp. 6 473–474 (1964); Фок В А "Работы А.А. Фридмана по теории тяготения Эйнштейна" УФН 80 353–356 (1963))

1st Alexander Friedmann International Seminar on Gravitation and Cosmology (22-26 June 1988, Leningrad). Many famous scientists attended the meeting: D. Sciama, A. D.Sakharov, S. Hawking, M. A. Markov, B. Carter, S. Deser, R. Ruffini

Figure 10. Moisei Alexandrovich Markov (the Chairman of the Scientific Organizing Committee of the Friedmann-100 Conference and Academician Secretary of Nuclear Division of Soviet Academy of Sciences) and Professor Remo Ruffini at the Conference (Leningrad, 1988).

Figure 11. Professor Remo Ruffini, Academician Andrei Dmitrievich Sakharov and professor Igor Dmitrievich Novikov at the Friedmann-100 Conference (Leningrad, 1988).

RELIKT-1 from Russian: РЕЛИКТ-1[a] (sometimes RELICT-1) was a Soviet cosmic microwave background anisotropy experiment launched on board the Prognoz 9 satellite on 1 July 1983. It operated until February 1984. It was the first CMB satellite (followed by the Cosmic Background Explorer in 1989) and measured the CMB dipole, the Galactic plane, and gave upper limits on the quadrupole moment.

A follow-up, RELIKT-2, would have been launched around 1993, and a RELIKT-3 was proposed, but neither took place due to the dissolution of the Soviet Union.

The Relikt Experiment

Prognoz 9, launched on 1 July 1983 into a high-apogee (700,000 km) orbit, included the Relikt-1 experiment to investigate the anisotropy of the CMB at 37 GHz, using a Dicke-type modulation radiometer. During 1983 and 1984 some 15 million individual measurements were made (with 10% near the galactic plane providing some 5000 measurements per point). The entire sky was observed in 6 months. The angular resolution was 5.5 degrees, with a temperature resolution of 0.6 mK. The galactic microwave flux was measured and the CMB dipole observed. A quadrupole moment was found between 17 and 95 microkelvin rms, with 90% confidence level. A map of most of the sky at 37 GHz is available.

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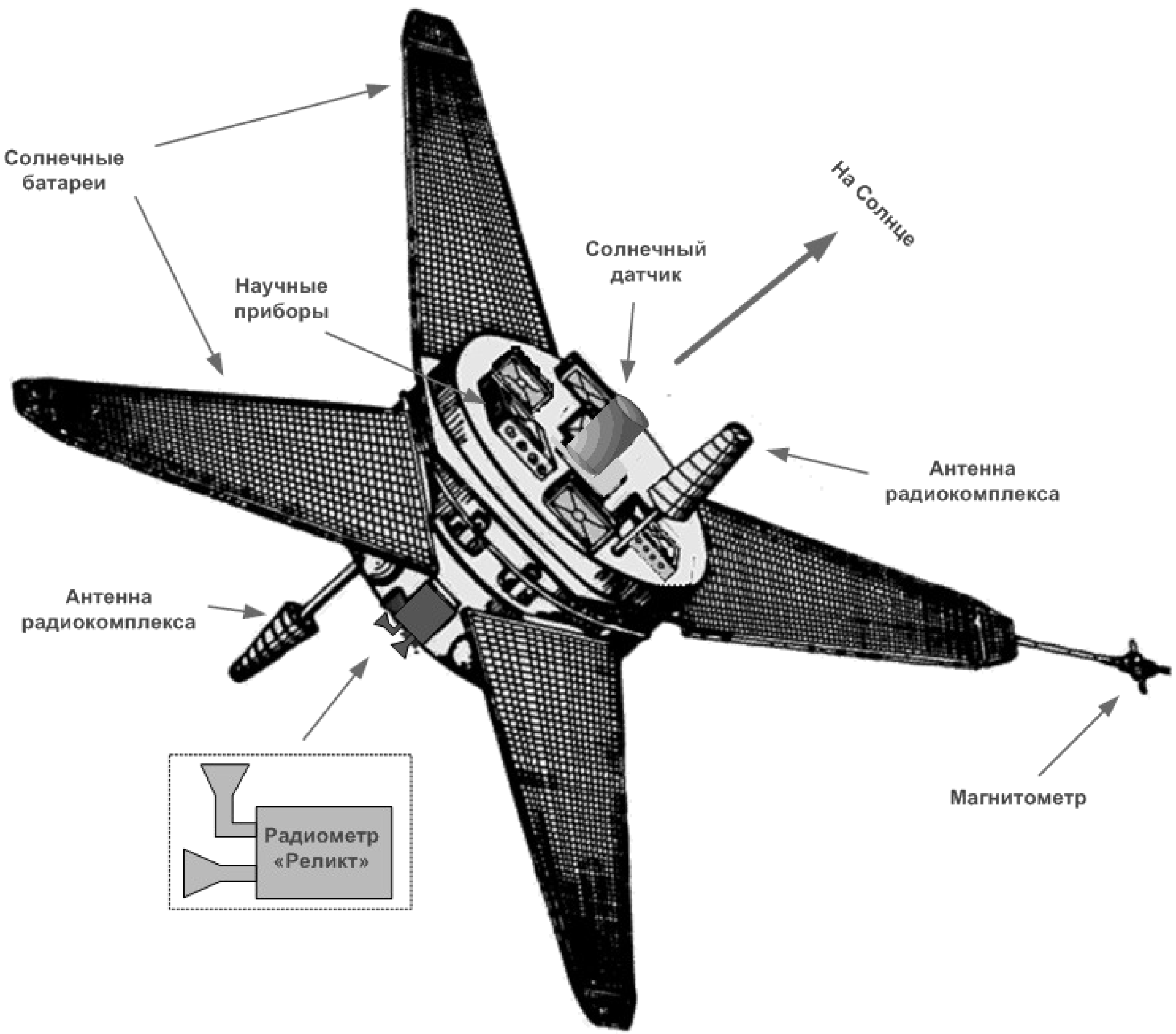
- I.A. Strukov, A.A. Brukhanov, D.P. Skulachev and M.V. Sazhin. **Pis'ma v Astronomicheskii Zhurnal v.18** (1992), 387 (in Russian, English version: Soviet Astronomy Letters 18 (1992), 153).
- I.A. Strukov, A.A. Brukhanov, D.P. Skulachev and M.V. Sazhin. **Mon. Not. R. Astron. Soc. 258** (1992), 37p.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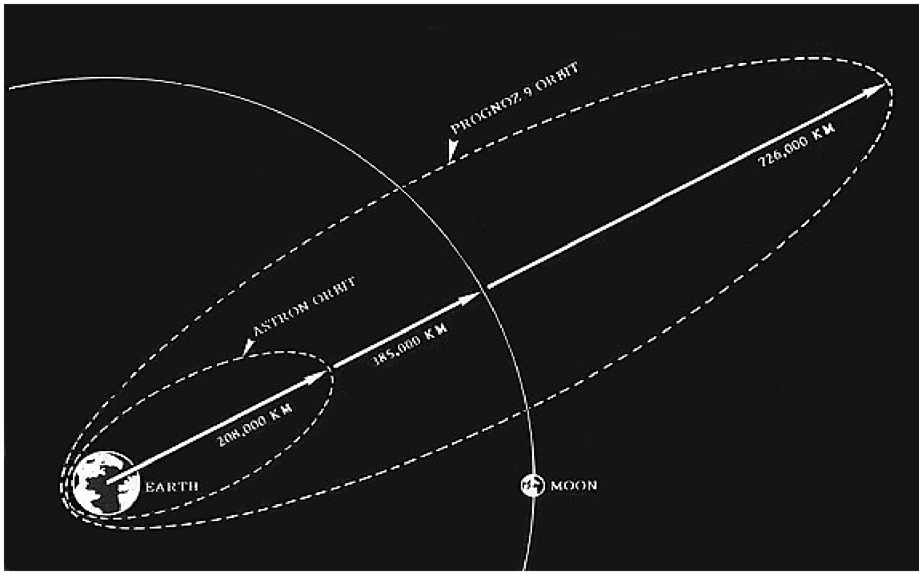
радиокомплекса
Радиометр
«Реликт»
Магнитометр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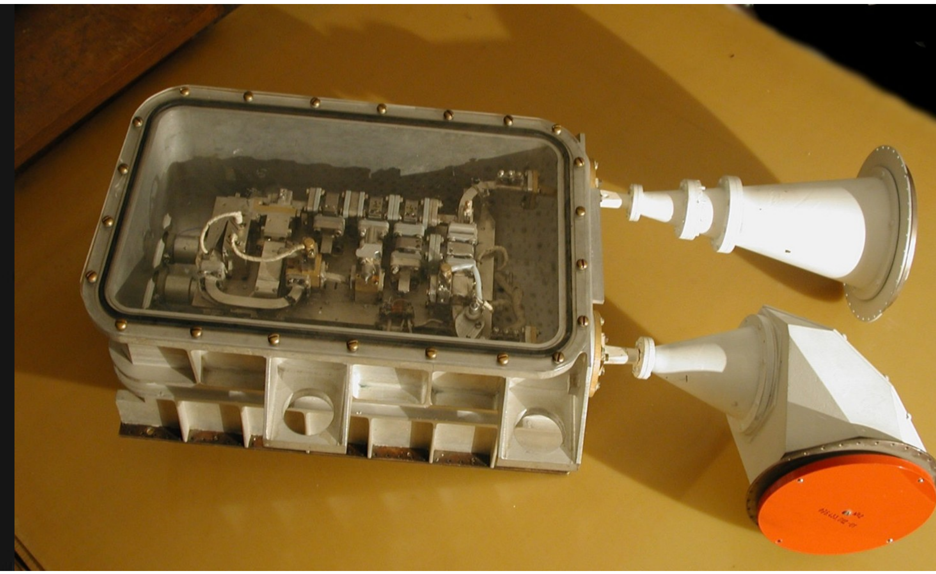

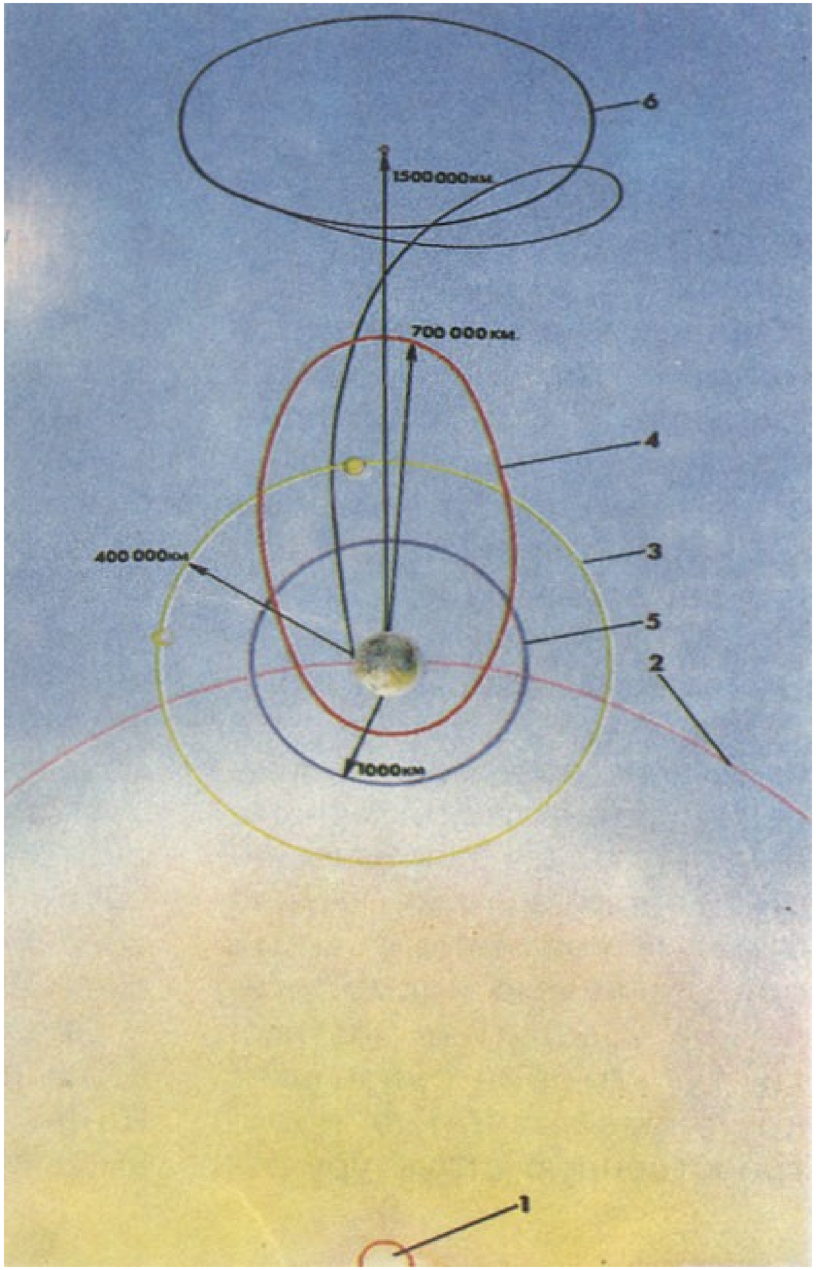
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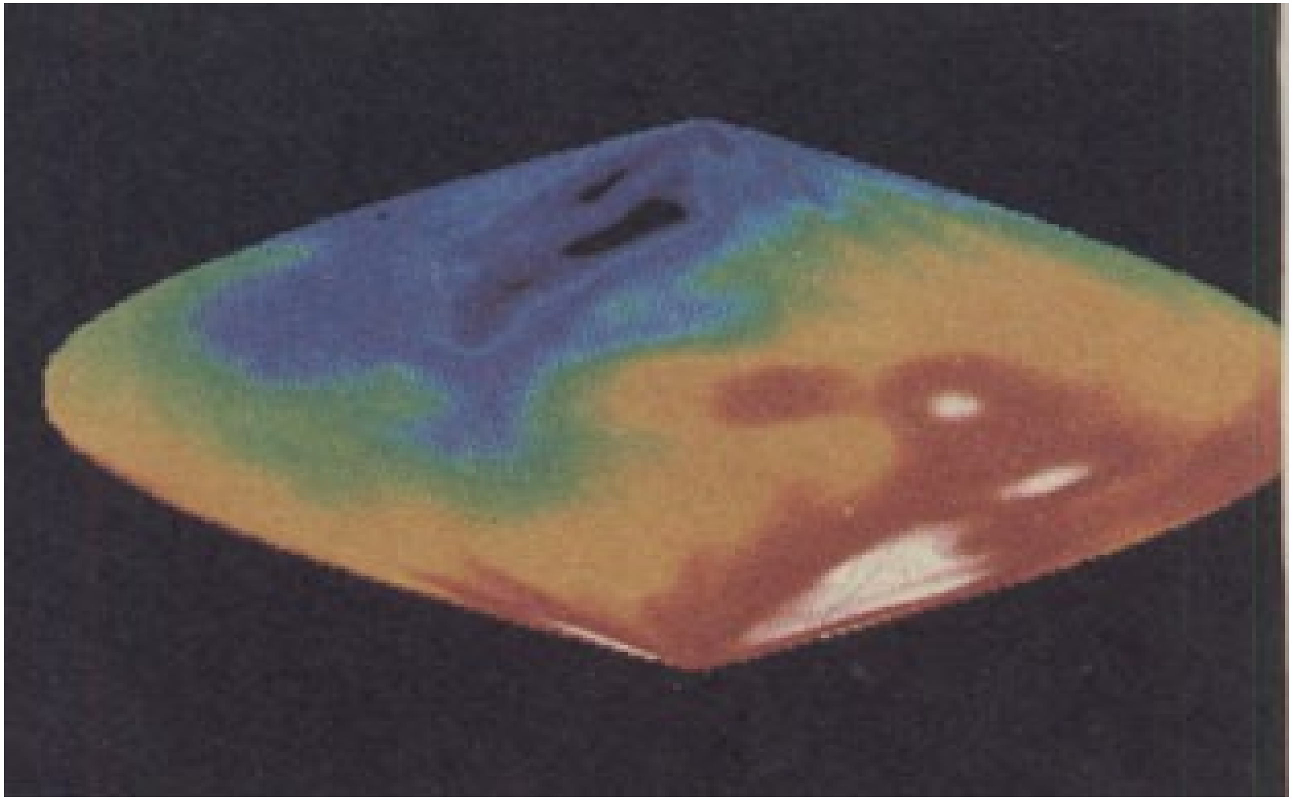
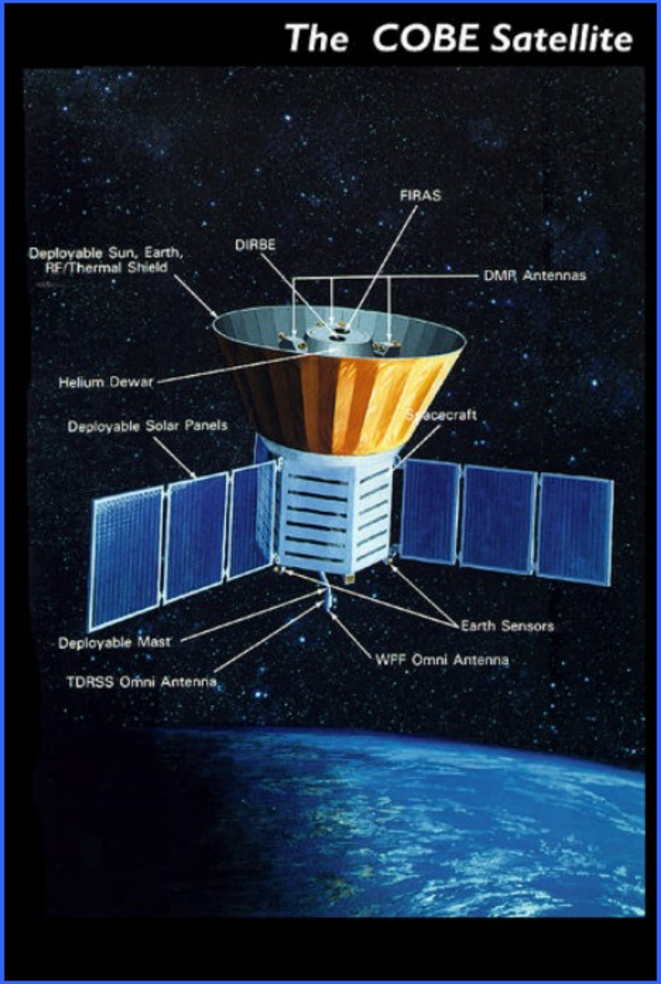
A radio-brightness map taken in the 8mm range during the Relict-1 experiment shows differences in the intensity of cosmic microwave background radiation caused by the movement of the Solar system at a speed of 350 km/s relative to the totality of all other galaxies (the dipole anisotropy).



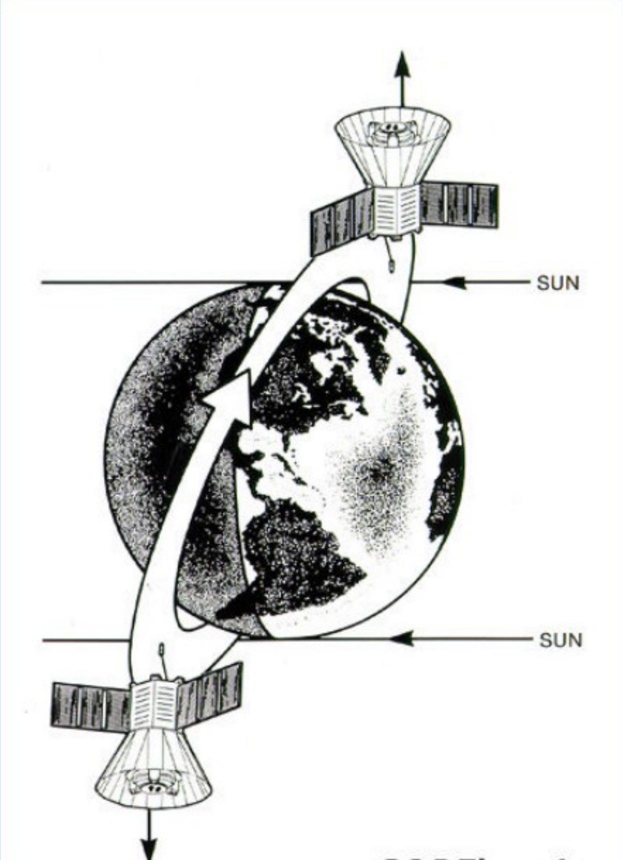
COBE Slide 2

Artist's conception of the COBE satellite in orbit, annotated with locations of scientific instruments, dewar, etc. The instruments are the Far Infrared Absolute Spectrophotometer (FIRAS), which made a precise measurement of the spectrum of the cosmic microwave background radiation; the Differential Microwave Radiometers (DMR), which detected for the first time and was used to characterize faint fluctuations in the cosmic microwave background corresponding to density structure in the early Universe; and the Diffuse Infrared Background Experiment (DIRBE),which obtained data that can be used to seek the cosmic infrared background and study the structure of the Milky Way Galaxy and the interstellar and interplanetary dust. The COBE was launched on November 18, 1989. All three instruments performed well while the helium cryogen supply lasted, until September 21, 1990. Thereafter, the FIRAS ceased operating, as did the DIRBE at wavelengths longer than 4.9 μm (micrometers, or "microns"). However, the DMR continued to operate normally, and the DIRBE continued to collectnear-infrared data with diminished sensitivity until these instruments were finally turned off on December 23, 1993.



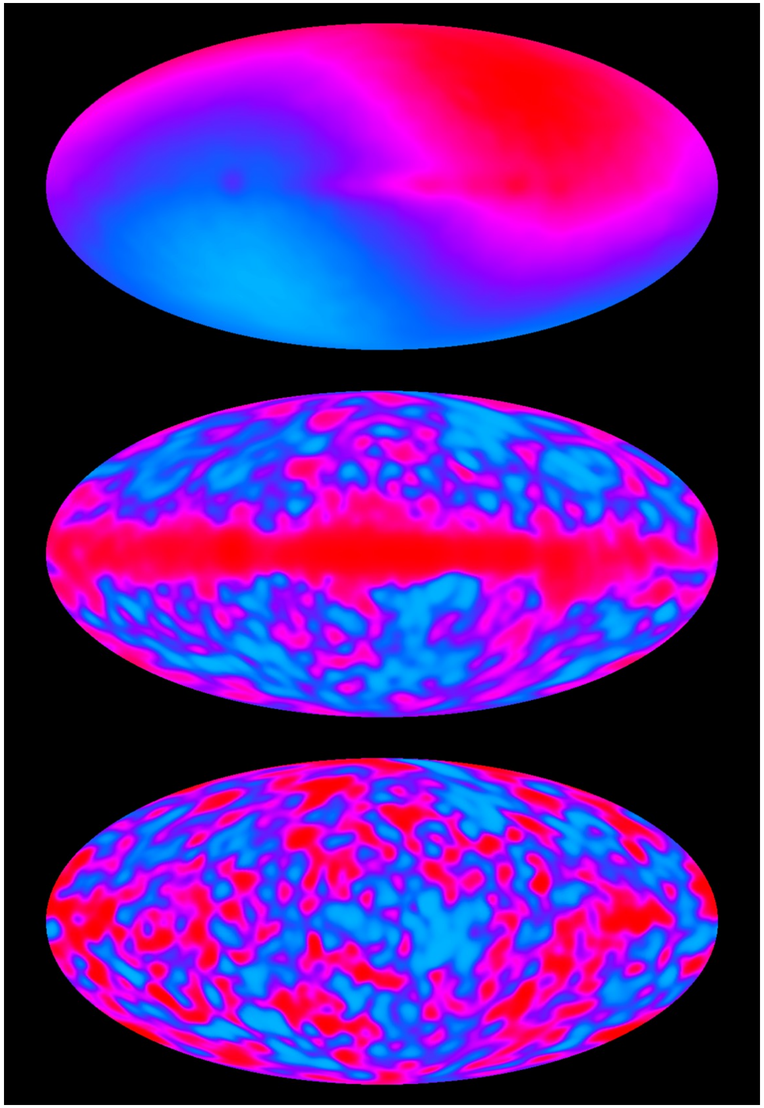
COBE Slide 3

The COBE orbit and spin axis orientation. The orbit nearly passes over the Earth's poles at an altitude of 900 km (559 miles). The orbital plane is inclined by 99 degrees to the Equator, causing the orbit to precess (turn) to follow the apparent motion of the Sun relative to the Earth. (The precession is caused by the Earth's equatorial bulge, which in turn results from the Earth's daily rotation about its axis.) Thus, the spin axis stays pointed almost perpendicular to the direction of the Sun and in a generally outward direction from the Earth. As the COBE orbits the Earth once every 103 minutes, it views a circle on the sky 94 degrees away from the Sun, and as the Earth moves around the Sun over the course of a year the COBE gradually scans the entire sky. The spacecraft rotates at 0.8 rpm. The FIRAS instrument is aligned with the spin axis. The DIRBE and DMR instruments point "off axis" and observe half the sky every orbit.

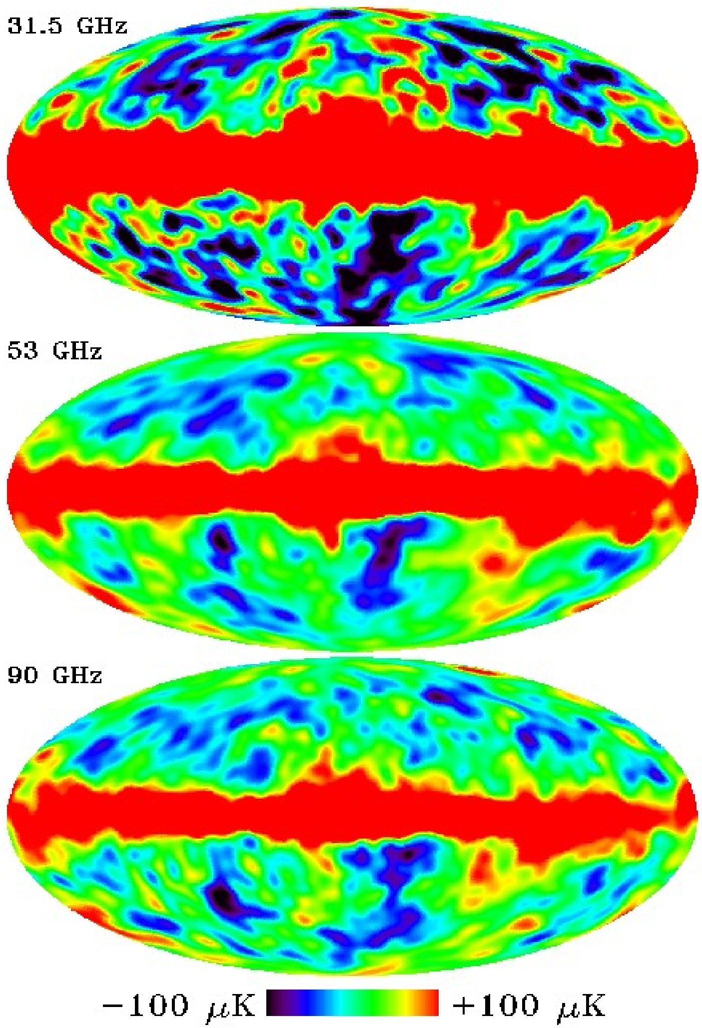


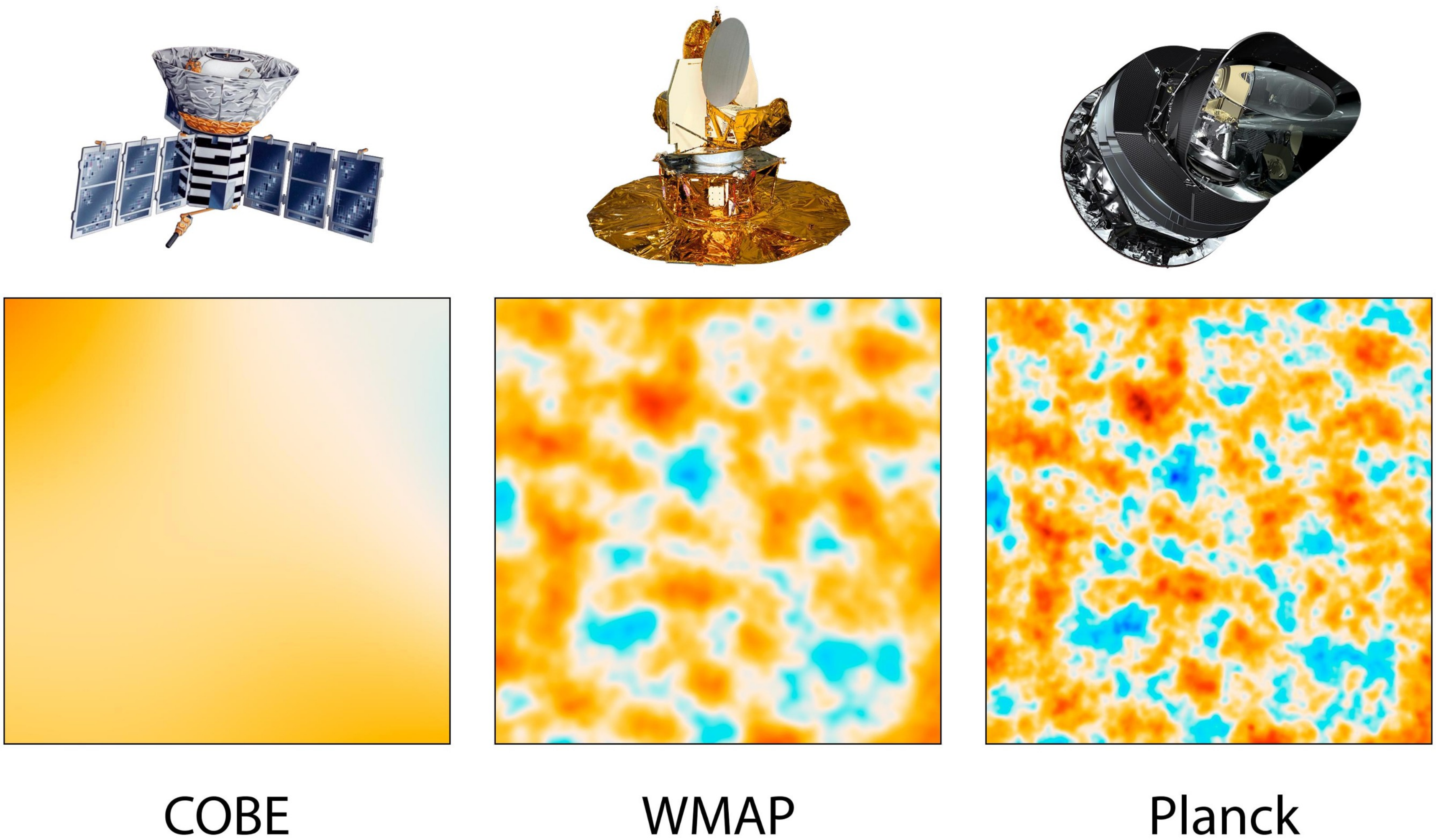
COBE's Orbit

Maps Based on Two Years of DMR Observation (COBE)



Maps Based on Observations Made Over the Entire 4-year Mission (COBE)




COBE
WMAP
Planck

Submission dates for COBE and Relikt-1

THE ASTROPHYSICAL JOURNAL, 396:L1–L5, 1992 September 1

STRUCTURE IN THE *COBE*[1] DIFFERENTIAL MICROWAVE RADIOMETER FIRST-YEAR MAPS

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E. KAITA,[7] T. KELSALL,[3] P. KEEGSTRA,[7] C. LINEWEAVER,[2] K. LOEWENSTEIN,[7] P. LUBIN,[8]
J. MATHER,[3] S. S. MEYER,[9] S. H. MOSELEY,[3] T. MURDOCK,[10] L. ROKKE,[7]
R. F. SILVERBERG,[3] L. TENORIO,[2] R. WEISS,[9] AND D. T. WILKINSON[11]
Received 1992 April 21; accepted 1992 June 12

ABSTRACT

The first year of data from the Differential Microwave Radiometers (DMR) on the *Cosmic Backgoround Explorer* (*COBE*) show statistically significant ($>7\ \sigma$) structure that is well described as scale-invariant fluctuations with a Gaussian distribution. The major portion of the observed structure cannot be attributed to known systematic errors in the instrument, artifacts generated in the data processing, or known Galactic emission. The structure is consistent with a thermal spectrum at 31, 53, and 90 GHz as expected for cosmic microwave background anisotropy.

The rms sky variation, smoothed to a total 10° FWHM Gaussian, is $30 \pm 5\ \mu$K ($\Delta T/T = 11 \times 10^{-6}$) for Galactic latitude $|b| > 20°$ data with the dipole anisotropy removed. The rms cosmic quadrupole amplitude is $13 \pm 4\ \mu$K ($\Delta T/T \approx 5 \times 10^{-6}$). The angular autocorrelation of the signal in each radiometer channel and cross-correlation between channels are consistent and give a primordial fluctuation power-law spectrum with index $n = 1.1 \pm 0.5$, and an rms-quadrupole–normalized amplitude of $16 \pm 4\ \mu$K ($\Delta T/T \approx 6 \times 10^{-6}$). These features are in accord with the Harrison-Zel'dovich (scale-invariant, $n = 1$) spectrum predicted by models of inflationary cosmology. The low overall fluctuation amplitude is consistent with theoretical predictions of the minimal level gravitational potential variations that would give rise to the observed present day structure.

Subject headings: cosmic microwave background — cosmology: observations

1. INTRODUCTION

The 2.73 K cosmic microwave background (CMB) is one of the most effective probes of the early universe. On large angular scales the CMB contains imprints of the primordial gravitational potential fluctuations (Sachs & Wolfe 1967) thought to be the origin of large-scale structure in the universe. The *COBE* DMR instrument, described by Smoot et al. (1990), is designed to measure the large-angular–scale anisotropy of the CMB. The instrument operates at three frequencies: 31.5, 53, and 90 GHz (wavelengths 9.5, 5.7, and 3.3 mm), chosen to be near the minimum in Galactic emission and near the CMB maximum. There are two nearly independent channels, A and B, at each frequency. The orbit and pointing of *COBE* result in a complete survey of the sky every 6 months while shielding the DMR from terrestrial and solar radiation (Boggess et al. 1992). Smoot et al. (1991) present preliminary results based on 6 months of data and Bennett et al. (1992a) describe the calibration procedures. This *Letter* describes results based upon the first year of DMR data. Companion papers discuss the treatment of systematic errors (Kogut et al. 1992), discuss the separation of cosmic and Galactic signals (Bennett et al. 1992b), and compare these data to other measurements and to models of structure formation through gravitational instability (Wright et al. 1992). These new results are consistent with, and substantially more sensitive than, the previously published large-angular–scale anisotropy measurements, in particular those of Princeton (Fixsen et al. 1983), Berkeley (Lubin et al. 1985), Relikt (Klypin et al. 1987), DMR preliminary results (Smoot et al. 1991), and Meyer, Page, & Cheng (1991).

2. DATA PROCESSING AND ANALYSIS

The DMR measures the difference in antenna temperature between regions of the sky separated by 60°. A baseline is

[1] The National Aeronautics and Space Administration/Goddard Space Flight Center (NASA/GSFC) is responsible for the design, development, and operation of the *Cosmic Background Explorer* (*COBE*). Scientific guidance is provided by the *COBE* Science Working Group. GSFC is also responsible for the development of the analysis software and for the production of the mission data sets.

[2] Lawrence Berkeley Laboratory, Space Sciences Laboratory, and Center for Particle Astrophysics, Building 50-351, University of California, Berkeley,

Submission date for Relikt-1

Mon. Not. R. astr. Soc. (1992) **258**, *Short Communication*, 37P–40P

The *Relikt-1* experiment – new results

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SUMMARY
We present new results from reduction of data from the space experiment *Relikt-1* (investigation of the anisotropy of the cosmic microwave background at 37 GHz). With 99 per cent confidence, an anomalous signal is detected in a region of area of about 1 sr, centred at RA= 1^h30^m, Dec. = $-10°$ ($l=150°$, $b=-70°$). The brightness temperature of the signal is $\Delta T = -71 \pm 43$ μK with 90 per cent confidence, including systematic errors. The nature of the signal cannot be explained by effects of the apparatus or by radio emission of known sources; there are reasons to believe that the signal has a cosmological origin. For a model of cosmological signal with scale-invariant spectrum, i.e. in terms of a power-law spectrum with $n=1$, we estimate, for the rms, a quadrupole component of $6\times10^{-6} < \Delta T_2/T < 3.3\times10^{-5}$ with 90 per cent confidence, including systematic errors.

Key words: artificial satellites, space probes – cosmic microwave background – cosmology: observations – large-scale structure of Universe.

1 INTRODUCTION

In this paper we discuss the results of processing additional data obtained from the space experiment *Relikt-1*. The survey was carried out at a frequency of 37 GHz with an angular resolution of 6°. Details of the experiment's configuration and data preparation were discussed in previous papers (Strukov & Skulachev 1987; Klypin *et al.* 1987; Strukov *et al.* 1988). We have not made any simplification to the model, and the data reprocessing now shows the presence of an anisotropy of the microwave background. The nature of this anisotropy will be discussed below.

2 DATA REDUCTION

We corrected the initial data by removing the modelled contribution of radiation from the Earth, Moon and Sun. We excluded all data in which this contribution was more than 0.5 mK (for the initial data, it corresponded to about 15 μK in the smoothed data, as described below). We also excluded results for which the difference between observed and modelled data was more than 10 per cent (during fast motion

signal after smoothing the data on the map. The smoothing value $T_{\rm smooth}$ on the map is determined from

$$T_{\rm smooth} = \frac{\sum T_j W_j \exp(-\varphi_j^2/2\varphi_0^2)}{\sum W_j \exp(-\varphi_j^2/2\varphi_0^2)},$$

where T_j is the measured value of brightness temperature, φ_j is the angular separation between the point at which the temperature is determined and the jth point of the map, W_j is the statistical weight (the number of measurements) of the jth point, and φ_0 is the smoothing angle. Assuming $W_j=0$ for a region between Galactic latitudes $b=\pm15°$, and also for those regions which are affected by earthshine and moonshine, makes the procedure insensitive to the Earth, Moon and Galactic radiation.

We modelled the signal which is determined by the Harrison–Zeldovich spectrum for primordial perturbations (Abbott & Wise 1984):

$$\langle \Delta T_l^2/T^2 \rangle = \pi\varepsilon_{\rm H}^2(2l+1)/2l(l+1), \qquad (1)$$

where l is the number of spherical harmonics, and $\varepsilon_{\rm H}$ is the amplitude of the metric fluctuation.

Anisotropy of the microwave background radiation

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Space Research Institute, Russian Academy of Sciences, Moscow and P. K. Shternberg State Astronomical Institute, Moscow

(Submitted January 19, 1992)

Pis'ma Astron. Zh. **18**, 387–395 (May 1992)

New results from analysis of data on the anisotropy of the background radiation at 37 GHz (spaceborne experiment Relikt 1) are presented. The relative magnitude of the quadrupole component was estimated with 90% confidence for an inflationary perturbation spectrum: $6\cdot10^{-6}<\Delta T_2/T<3.3\cdot10^{-5}$. An anomaly of the microwave radiation has been found, with 99% confidence, in a region with area $\simeq 1$ sr near the point with coordinates $\alpha\simeq 1^h30^m$ and $\delta\simeq -10°$ ($l = 150°$ and $b = -70°$). The magnitude of this anomaly is $\Delta T_b = -71\pm43$ μK with 90% confidence. We discuss possible sources of the anomaly.

Introduction. This paper is devoted to the results of a follow-on analysis of data from scans of the celestial sphere at 37 GHz in the Relikt 1 spaceborne experiment on the measurement of the background radiation anisotropy (Strukov and Skulachev, 1986; Klypin et al., 1987; Strukov et al., 1988).

The data analysis performed thus far has not revealed a cosmological signal. Only an upper limit on the possible strength of such a signal has been estimated. Such estimates are made primarily by comparing the experimental data, i.e., the signal plus noise, with very accurately determined instrumental noise. In order to make reliable estimates, it is then important to know exactly how the signal and noise are transformed in all units of the experimental apparatus and at all stages of subsequent data processing. In preceding works a number of effects were taken into account approximately. In constructing a map of the celestial sphere we carefully calculated the correlation of separate measurements, and this made it possible to determine more accurately the instrumental noise in the radio map obtained. The noise level was reduced mainly by properly taking into account radiometer sampling by the satellite's telemetry system and by modeling completely the procedure for subtracting out the dipole component of the radiation.

We performed signal analysis and estimation after smoothing the data on the map, using a much larger smoothing parameter than in our previous work (Klypin et al., 1987; Strukov et al., 1988).

Signal analysis on the sphere. The signal $T(\theta, \varphi)$ on the sphere can be represented as an expansion in spherical harmonics $Y_{l,m}(\theta, \varphi)$:

$$T(\theta,\varphi)=\sum a_l^m Y_{l,m}(\theta,\varphi)=\frac{1}{\sqrt{\pi}}\sum_{l=0}^{\infty}\sum_{m=0}^{l}\frac{1}{\sqrt{1+\delta_{0m}}}\times\sqrt{\frac{(2l+1)(l-m)!}{2(l+m)!}}P_l^m(\cos\theta)(a_l^{+m}\cos m\varphi+a_l^{-m}\sin m\varphi),$$

where $\delta_{0m} = 1$ if $m = 0$ and $\delta_{0m} = 0$ otherwise; $P_l^m(\cos\theta)$ are the associated Legendre polynomials of degree l and order m; a_l^m are the coefficients in the multipole expansion; and, θ and φ are the polar and azimuthal angles.

The variance σ^2 of the signal on the sphere can be represented as follows:

$$\sigma^2=\frac{1}{4\pi}\sum_{l=0}^{\infty}\sum_{m=-l}^{l}(a_l^m)^2=\sum_{l=0}^{\infty}\Delta T_l^2,$$

where $\Delta T_l^2 = (1/4\pi)\sum_{m=-l}^{l}(a_l^m)^2$ is in the lth spherical harmonic.

For subsequent calculations we employed the signal corresponding to the Harrison–Zel'dovich spectrum for primordial perturbations (Abbott and Wise, 1984; Starobinski, 1983). For such a spectrum

$$\langle\Delta T_l^2/T^2\rangle=\pi\varepsilon_H^2(2l+1)/2l(l+1), \quad (1)$$

where T is the temperature of the microwave background, l is the number of the spherical harmonic, $\langle\ldots\rangle$ denotes the expectation value, and ε_H is the amplitude of fluctuations at the moment the horizon is crossed.

The signal-to-noise ratio for such a signal can be improved by reducing the high-frequency noise in the map of the experimental data by means of additional smoothing.

Smoothing was performed as follows. The smoothed value T_{smooth} at a given point on the map was determined from the formula

$$T_{smooth}=\left(\sum T_j\cdot W_j\cdot\exp(-\varphi_j^2/2\varphi_0^2)\right)/\sum W_j\cdot\exp(-\varphi_j^2/2\varphi_0^2),$$

where T_j is the measured value of the brightness temperature; φ_j is the angular distance from the given point to the jth point in the region of smoothing; W_j is the statistical weight of the jth point, equal to the number of measurements; and φ_0 is the smoothing parameter.

The summation extended over all points at which

$$\varphi_j<\varphi_{max}=3\varphi_0.$$

The width of the chosen smoothing function of half-maximum is $2.355\varphi_0$.

Analysis of variance. Analysis of variance addressed the problem of testing the hypothesis that a signal is present in the data and the problem of estimating the parameters of that signal.

Two approaches are possible, which differ in the method employed for representing the signal. In the first approach the signal is assumed to be deterministic, and estimates are given for the experimentally measured quantities. Such estimates have the smallest confidence interval, but they depend on the specific configuration of the measured signal and they do not permit judging the entire spectrum, and for this reason they do not make it possible to properly compare the measured values with the theoretical predictions.

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Physics – Uspekhi **53** (4) 373 – 376 (2010)

PHYSICS OF OUR DAYS

PACS numbers: **95.55.–n**, **95.75.–z**, 98.80.Es

Cosmic microwave background anisotropy data correlation in WMAP and Relikt-1 experiments

D P Skulachev

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Contents

Abstract. **A comparison is made of cosmic microwave background anisotropy data obtained from the WMAP satellite in 2001 – 2006 and from the Relikt-1 satellite in 1983 – 1984. It is shown that the low-temperature area found by Relikt-1 is the location of the 'coldest spot' of the WMAP radiomap. The mutual correlation of the two datasets is estimated and found to be positive for all sky regions surveyed. The conclusion is made that with the 98% probability, the Relikt-1 experiment had detected the same signal that was later identified by WMAP. A discussion is given of whether the Relikt-1 experiment parameters were chosen correctly.**

1. Introduction

The anisotropy of cosmic microwave background (CMB) radiation was discovered in sky surveys carried out by dedicated artificial satellites [1, 2]. By the middle of 2009, the CMB has been explored by three space experiments: Relikt-1 (USSR, 1983–1984), COBE (Cosmic Background Explorer) (USA, 1989–1993), and WMAP (Wilkinson Microwave Anisotropy Probe) (USA, launched in 2001). In May 2009, the Planck European space mission with a similar research task was successfully launched.

The sensitivity of the Relikt-1 experiment was limited by the technical capabilities of that time and can be considered rather modest according to modern criteria. However, that sensitivity proved to be sufficient to discover and measure the CMB anisotropy parameters. The dipole anisotropy was detected and the amplitude of the quadrupole anisotropy for a given perturbation spectrum was measured [3]. A low-temperature area — a 'cold spot' — was found on the sky radiomap [1]. The measurements were carried out only at one frequency and on the verge of the sensitivity limit, and therefore the results obtained needed to be confirmed by more precise measurements.

The American satellite COBE was launched six years after Relikt-1 with better equipment. Estimates of the dipole and quadrupole anisotropy for a given spectrum obtained by both satellites were found to be consistent within error. The cold spot found by Relikt-1 was not confirmed by COBE [4, 5], but the signal-to-noise ratio on the COBE radiomap was rather low in this area of the sky.

Results of any observations can be reliably confirmed or rejected only by analyzing independent experimental data with a good signal-to-noise ratio. At present, such data has been obtained by the WMAP satellite during five years of continuous measurements [6]. In what follows, we present the results of a comparison of the WMAP and Relikt-1 experimental data.

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2. The WMAP data used in the analysis

The central frequency of the Ka and Q channels of the WMAP satellite coincides with the working frequency of the Relikt-1 radiometer, and we therefore use the brightness temperatures in the Ka and Q channels of the WMAP satellite for the subsequent analysis.

3. The 'cold spot'

Figure 1 shows a part of the WMAP radiomap in ecliptic coordinates. The data was smoothed with an angular

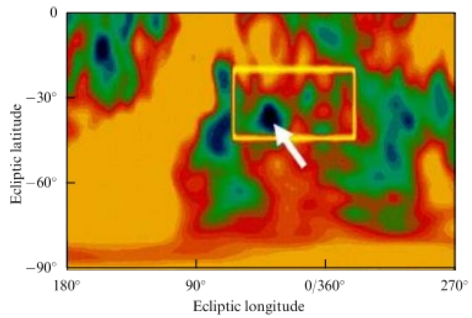


Figure 1. The 'Spot' of WMAP (marked with the arrow) and the 'cold' spot area of Relikt-1 (inside the white quadrangle).

resolution of 15°. The brightness temperature of regions near the galactic plane is conventionally set to zero. The dark color marks low-temperature areas. The white quadrangle shows the area where Relikt-1 found the coldest spot. The coordinates of the quadrangle are taken from [1].

It can be seen that several cold points fall within the area shown, with one of them (marked by the arrow in Fig. 1) being the famous 'Spot,' the coldest spot on the entire WMAP radiomap [1]. The Spot has ecliptic coordinates $\lambda = 39°$, $\beta = -37°$ and galactic coordinates $l = 209°$, $b = -57°$. The low-temperature area on the Relikt-1 map was singled out using additional data averaging. In this procedure, cold points apparently joined together into a single big spot, which was actually discovered. The parameters of the measured brightness temperature minimum are given in [1]. The exact location of the spot itself was not then measured due to a high noise level, which is why an extended area inside the quadrangle was marked.

We note that a part of the cold area on the Relikt-1 radiomap near zero ecliptic longitudes has the brightness temperature close to zero on the WMAP sky map. Supposedly, it is exactly this region that was studied in [4, 5], where it was concluded that the Relikt-1 data are inconsistent with the COBE data. However, the list of the coldest spots on the COBE sky map [8] does not include the Spot itself, the coldest object later discovered by WMAP.

4. Dipole component

The CMB dipole component parameters determined from the WMAP data [9] and the Relikt-1 data [3] are given in Table 1. The errors correspond to a 90% confidence level. Thermodynamic values of the brightness temperature are used.

Table 1 shows that the results of two experiments are consistent within errors. A small (about 6%) difference in the dipole amplitude can be explained by a systematic calibration error of the Relikt-1 radiometer.

Table 1. Estimate of the dipole CMB anisotropy.

Experiment	Dipole component	
	Amplitude	Galactic coordinates of the maximum

5. Higher anisotropy components

In the Relikt-1 data, the amplitudes of higher anisotropy harmonics were found by statistical modeling under the assumption of the Harrison–Zeldovich primordial perturbation spectrum. An estimate is given for the rms value of the quadrupole component ($Q_{\text{rms-ps}}$) for this spectrum [1].

In the WMAP data, the quadrupole component was determined as [10]

$$Q_{\text{rms-ps}} = \sqrt{\frac{5C_2}{4\pi}}\,, \tag{1}$$

with C_2 calculated as

$$C_2 = \frac{2\pi}{6} \sum_{l=2}^{15} \frac{C_l l(l+1)/2\pi}{14}\,, \tag{2}$$

where $C_l l(l+1)/2\pi$ is the lth component of the anisotropy power spectrum [11]. The summation limits here approximately correspond to the transfer function of the Relikt-1 radiometer, taking smoothing into account. The averaging over l in formula (2) is used to reduce uncertainties in the estimate of C_2, taking into account that $C_l l(l+1)$ is independent of l for the Harrison–Zeldovich spectrum.

The corresponding values (in microkelvins) are presented in Table 2. For Relikt-1, a 90% confidence level for the interval is given.

Table 2. Estimates of higher-anisotropy components.

Experiment	Quadrupole component $Q_{\text{rms-ps}}$
WMAP	18.9 μK
Relikt-1	16.5 – 90 μK

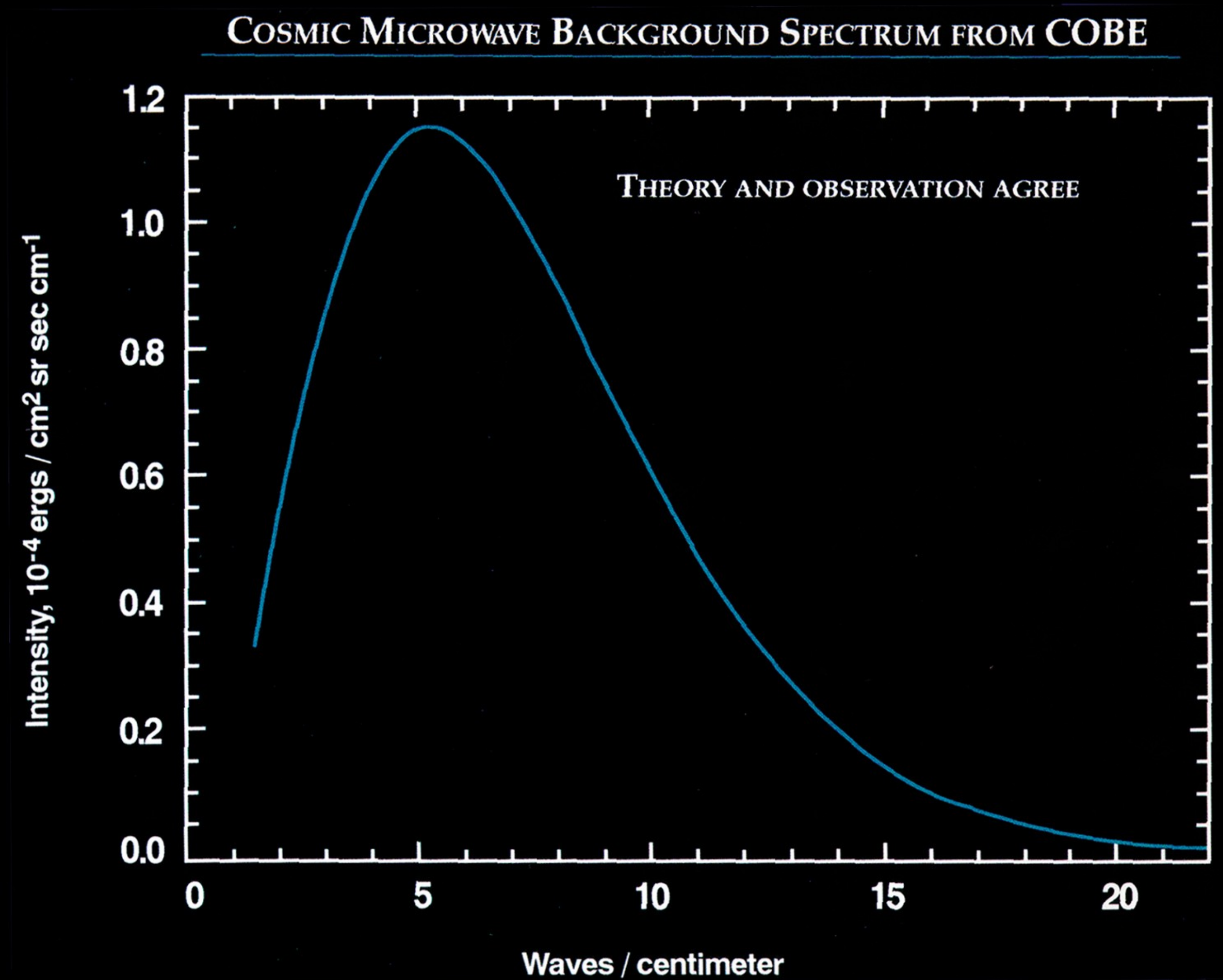
It follows from Table 2 that the data of both experiments are consistent within errors.

We note that the values in Table 2 give model-dependent estimates of the entire anisotropy and not the measured quadrupole amplitudes. The measured quadrupole amplitudes would be such if the measured anisotropy were generated by primordial fluctuations with the Harrison–Zeldovich spectrum.

6. Signal detected by Relikt-1

Although the anisotropy estimates made by Relikt-1 are confirmed by the WMAP data, this could be considered purely coincidental because the spectrum and the form of the signal discovered by Relikt-1 have not actually been determined. The anisotropy was calculated in [1] from the dispersion analysis using a small excess of measured values against pure noise, and it is not at all clear whether such an excess is due to a real signal or to quite different reasons, e.g., electric interference or external radiation. Therefore, a more detailed study of the structure of the signal measured by Relikt-1 is in order.

7. Method of the signal structure study


COSMIC MICROWAVE BACKGROUND SPECTRUM FROM COBE
THEORY AND OBSERVATION AGREE
Intensity, 10-4 ergs / cm2 sr sec cm-1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Waves / centimeter

Erast Borisovich Gliner 26.01.1923 (Kyiv) – 16.11.1921 (San-Francisco)

A. D. Sakharov on his first cosmological papers published since 1960s: “In one of the hypothetical equations of state that I have considered, the energy density tends to a constant value as the density of matter tends to infinity. That is, in the limit, the energy density does not depend on the density of matter. The pressure is negative,and the substance is stretched. Such an equation of state leads to the expansion of the universe according to the law of exponential function. Independently,and with greater certainty, Gliner wrote about the same thing in the same years”.

It means that EBG considered vacuum energy in cosmological theories many years before an introduction of inflationary cosmology proposed by A. A. Starobinsky, A. Guth, A. D. Linde and many years before the discovery of the accelerated expansion of the Universe in 1998 and the introduction of dark energy as a component which determines a behaviour of the Universe.

Figure 3. Early 1970s. Embankment of the Neva river in Leningrad (now St. Petersburg). From Gliner family archive; courtesy of Arkady and Bella Gliner.

In my description of Gliner's scientific biography I essentially use

Yakovlev, D.; Kaminker, A. . Universe **2023**, 9, 46.

https://doi.org/10.3390/universe9010046

and

A. D. Chernin

https://ufn.ru/tribune/trib118.pdf

In 1926, Erast and his mother moved to Leningrad

In the summer of 1940 EBG graduated from school and was admitted to the Chemistry Department of Leningrad State University (LSU)

EBG spent the coldest and hungriest winter of 1941–1942 in Leningrad

At the end of April 1942, EBG insisted on enlisting and was assigned to artillery. He was awarded the Order of the Red Star. He was wounded three times. The last wound to the right arm on 30 October 1943 required amputation and he was hospitalized for several months.

He was then released from the army and returned to Leningrad in the summer of 1944. For medical reasons, he could not work with chemicals and was unable to continue his chemistry education. He was admitted to the Physics Department of LSU. He had to start from the first year, because the programs of the Chemistry and Physics Departments were different.

On 19 May 1945, EBG was sentenced by the military tribunal unde Articles 58-10, part 2 and 58-11 to 10 years with subsequent five-year suppression of civic rights and no right to appeal.

In 1945 -- 1952, EBG worked at the Special Construction Bureau (OKB-172) in Kresty designing naval gun systems.

In 1952, he was transferred to Moscow, to KB-1 (S. Berya was one of heads of the KB). Gliner was released on 25 April 1954. He returned to Leningrad but was legally forbidden to live there for five years.

In May 1955, Gliner was offered a permanent job at a construction bureau P.O.691 (Leningrad branch of KB-1), and he accepted the position.

By the middle of 1963, he had passed all the exams and defended his thesis “Investigation of the singularity of Schwarzschild’s external solution”. In June 1963 he graduated from LSU (diploma with honors)

In 1962 the Publishing House of “Vysshaya Shkola” published a textbook “Differential Equations of Mathematical Physics” co-authored by N. S. Koshlyakov, E. B. Gliner and M. M. Smirnov.

By the middle of 1963, he had passed all the exams and defended his thesis “Investigation of the singularity of Schwarzschild’s external solution”.
In June 1963 he graduated from LSU (diploma with honors)

In 1963 B. P. Konstantinov sent a request to LSU with the proposal to employ him.

In 1965 EBG published the first paper in Soviet JETP.

In 1970 he prepared PhD thesis.

V. L. Ginzburg, V. A. Fock and A. D. Sakharov supported Gliner’s studies and they proposed to present Gliner’s thesis as D Sc thesis. V. A. Fock and A. D. Sakharov were ready to be opponents.

Ioffe LPTI administration insisted on two points. First, either Sakharov is removed from the list of opponents, in which case the defense is allowed, perhaps even as doctoral; otherwise, all dissertation documents are taken away by administration and there will be no defence at all. Second, to frighten Gliner, it was said that the GR theory (Gliner's topic) was not included in the work plan of the Ioffe Institute; accordingly, the topic should be changed, otherwise Gliner could lose his job.

It was unbelievable cruelty, but nobody protested because almost nobody knew. As for E. Gliner, it was a matter of principle not to disregard Sakharov. He refused, and his dissertation documents were locked away at the institute.

Conclusion

Very often our scientific community was not active in promotion of achievements of compatriots therefore, the achievements were underestimated or even not known in other countries.

I listed people whose achievements were underestimated:

V. K. Frederics, A. A. Friedman, G. Lemaitre, G. Gamow, S. E. Khaikin, T. A. Shmaonov, I. A. Strukov and Relikt-1 group, E. B. Gliner...

Backup slides

From Paradise Lost by A. A. Migdal

"...Some of us turned out to be more equal than others, and our Western friends, regardless how hard they tried to help us in isolation, could do nothing with the laws of a free market – if you are not present to explain and defend your ideas they will get stolen or simply ignored and reinvented..."

М. И. Монастырский (2009) “...К слову сказать, у нас (в России) очень любят причитать по поводу недооценки русских учёных на Западе. Но тщательный анализ реальных фактов показывает, что больше всего признанию русских (советских) учёных мешают другие русские (советские) учёные...”

M. I. Monastyrsky (2009) "...By the way, we (in Russia) are very fond of lamenting the underestimation of Russian scientists in the West. Russian Russian (Soviet) scientists are the ones who hinder the recognition of Russian (Soviet) scientists the most, however, a careful analysis of the real facts shows...”

Massive graviton theories

- M. Fierz and W.Pauli-1939
- Zakharov; Veltman, van Dam – 1970
- Vainshtein - 1972
- Boulware, Deser -- 1972
- Logunov, Mestvirishvili, Gershtein et al. (RTG)
- Visser – 1998 (review on such theories)
- Rubakov, Tinyakov – 2008
- de Rham et al.—2011 -- 2016

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An IOP and SISSA journal

Constraining the range of Yukawa gravity interaction from S2 star orbits II: bounds on graviton mass

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Abstract. Recently LIGO collaboration discovered gravitational waves [1] predicted 100 years ago by A. Einstein. Moreover, in the key paper reporting about the discovery, the joint LIGO & VIRGO team presented an upper limit on graviton mass such as $m_g < 1.2 \times 10^{-22} eV$ [1] (see also more details in another LIGO paper [2] dedicated to a data analysis to obtain such a small constraint on a graviton mass). Since the graviton mass limit is so small the authors concluded that their observational data do not show violations of classical general relativity. We consider another opportunity to evaluate a graviton mass from phenomenological consequences of massive gravity and show that an analysis of bright star trajectories could bound graviton mass with a comparable accuracy with accuracies reached with gravitational wave interferometers and expected with forthcoming pulsar timing observations for gravitational wave detection. It gives an opportunity to treat observations of

JCAP05(2016)045

 doi:10.1088/1475-7516/2016/05/045

Constraints on graviton mass from S2 trajectory

- AFZ, D. Borka, P. Jovanovic, V. Borka Jovanovic gr-qc: 1605.00913v; JCAP (2016) :
- $\lambda_g > 2900$ AU = 4.3×10^{11} km with P=0.9 or
- $m_g < 2.9 \times 10^{-21}$ eV $=5.17 \times 10^{-54}$ g
- Hees et al. PRL (2017) slightly improved our estimates with their new data $m_g < 1.6 \times 10^{-21}$ eV (see discussion below)

graviton MASS

INSPIRE search

It is likely that the graviton is massless. More than fifty years ago Van Dam and Veltman (VANDAM 1970), Iwasaki (IWASAKI 1970), and Zakharov (ZAKHAROV 1970) almost simultaneously showed that in the linear approximation a theory with a finite graviton mass does not approach GR as the mass approaches zero. Attempts have been made to evade this "vDVZ discontinuity" by invoking modified gravity or nonlinear theory by De Rahm (DE-RHAM 2017) and others. More recently, the analysis of gravitational wave dispersion has led to bounds that are largely independent of the underlying model, even if not the strongest. We quote the best of these as our best limit.

Experimental limits have been set based on a Yukawa potential (YUKA), dispersion relation (DISP), or other modified gravity theories (MGRV).

The following conversions are useful: 1 eV = 1.783×10^{-33} g = $1.957 \times 10^{-6} m_e$; λ_C = $(1.973 \times 10^{-7}$ m$)\times(1$ eV$/m_g)$.

VALUE (eV)	DOCUMENT ID		TECN	COMMENT
$< 5 \times 10^{-23}$	[1] ABBOTT	2019	DISP	LIGO Virgo catalog GWTC-1
• • We do not use the following data for averages, fits, limits, etc. • •				
$< 3.2 \times 10^{-23}$	[2] BERNUS	2020	YUKA	Planetary ephemeris INPOP19a
$< 2 \times 10^{-28}$	[3] SHAO	2020	DISP	Binary pulsar Galileon radiation
$< 7 \times 10^{-23}$	[4] BERNUS	2019	YUKA	Planetary ephemeris INPOP17b
$< 3.1 \times 10^{-20}$	[5] MIAO	2019	DISP	Binary pulsar orbital decay rate
$< 1.4 \times 10^{-29}$	[6] DESAI	2018	YUKA	Gal cluster Abell 1689
$< 5 \times 10^{-30}$	[7] GUPTA	2018	YUKA	Using SPT-SZ
$< 3 \times 10^{-30}$	[7] GUPTA	2018	YUKA	Using Planck all-sky SZ
$< 1.3 \times 10^{-29}$	[7] GUPTA	2018	YUKA	Using redMaPPer SDSS-DR8
$< 6 \times 10^{-30}$	[8] RANA	2018	YUKA	Weak lensing in massive clusters
$< 8 \times 10^{-30}$	[9] RANA	2018	YUKA	SZ effect in massive clusters
$< 1.0 \times 10^{-23}$	[10] WILL	2018	YUKA	Perihelion advances of planets
$< 7 \times 10^{-23}$	[1] ABBOTT	2017	DISP	Combined dispersion limit from three BH mergers
$< 1.2 \times 10^{-22}$	[1] ABBOTT	2016	DISP	Combined dispersion limit from two BH mergers
$< 2.9 \times 10^{-21}$	[11] ZAKHAROV	2016	YUKA	S2 star orbit
$< 5 \times 10^{-23}$	[12] BRITO	2013	MGRV	Spinning black holes bounds
$< 6 \times 10^{-32}$	[13] GRUZINOV	2005	MGRV	Solar System observations
$< 6 \times 10^{-32}$	[14] CHOUDHURY	2004	YUKA	Weak gravitational lensing
$< 9.0 \times 10^{-34}$	[15] GERSHTEIN	2004	MGRV	From Ω_{tot} value assuming RTG
$< 8 \times 10^{-20}$	[16,17] FINN	2002	DISP	Binary pulsar orbital period decrease
$< 7 \times 10^{-23}$	TALMADGE	1988	YUKA	Solar system planetary astrometric data
$< 1.3 \times 10^{-29}$	[18] GOLDHABER	1974	YUKA	Rich clusters
$< 7 \times 10^{-28}$	HARE	1973	YUKA	Galaxy
$< 8 \times 10^{4}$	HARE	1973	YUKA	2γ decay

[1] ABBOTT 2019 , ABBOTT 2017 , and ABBOTT 2016 limits assume a dispersion relation for gravitational waves modified relative to GR.

[2] BERNUS 2020 use the latest solution of the ephemeris INPOP (19a) in order to improve the constraint in BERNUS 2019 on the existence of a Yukawa suppression to the Newtonian potential, generically associated to a gravitons mass.

[3] SHAO 2020 sets limit, 95% CL, based on non-observation of excess gravitational radiation in 14 well-timed binary pulsars in the context of the cubic Galileon model.

[4] BERNUS 2019 use the planetary ephemeris INPOP 17b to constraint the existence of a Yukawa suppression to the Newtonian potential, generically associated to a gravitons mass.

[5] MIAO 2019 90% CL limit is based on orbital period decay rates of 9 binary pulsars using a Bayesian prior uniform in graviton mass. Limit becomes $< 5.2 \times 10^{-21}$ eV for a prior uniform in $\ln(m_g)$.

[6] DESAI 2018 limit based on dynamical mass models of galaxy cluster Abell 1689.

VALUE (eV) DOCUMENT ID TECN COMMENT

[7] GUPTA 2018 obtains graviton mass limits using stacked clusters from 3 disparate surveys.

[8] RANA 2018 limit, 68% CL, obtained using weak lensing mass profiles out to the radius at which the cluster density falls to 200 times the critical density of the Universe. Limit is based on the fractional change between Newtonian and Yukawa accelerations for the 50 most massive galaxy clusters in the Local Cluster Substructure Survey. Limits for other CL's and other density cuts are also given.

[9] RANA 2018 limit, 68% CL, obtained using mass measurements via the SZ effect out to the radius at which the cluster density falls to 500 times the critical density of the Universe for 182 optically confirmed galaxy clusters in an Altacama Cosmology Telescope survey. Limits for other CL's and other density cuts are also given.

[10] WILL 2018 limit from perihelion advances of the planets, notably Earth, Mars, and Saturn. Alternate analysis yields $< 6 \times 10^{-24}$.

[11] ZAKHAROV 2016 constrains range of Yukawa gravity interaction from S2 star orbit about black hole at Galactic center. The limit is $< 2.9 \times 10^{-21}$ eV for $\delta = 100$.

[12] BRITO 2013 explore massive graviton (spin-2) fluctuations around rotating black holes.

[13] GRUZINOV 2005 uses the DGP model (DVALI 2000) showing that non-perturbative effects restore continuity with Einstein's equations as the gravition mass approaches zero, then bases his limit on Solar System observations.

[14] CHOUDHURY 2004 concludes from a study of weak-lensing data that masses heavier than about the inverse of 100 Mpc seem to be ruled out if the gravitation field has the Yukawa form.

[15] GERSHTEIN 2004 use non-Einstein field relativistic theory of gravity (RTG), with a massive graviton, to obtain the 95% CL mass limit implied by the value of Ω_{tot} = 1.02 ± 0.02 current at the time of publication.

[16] FINN 2002 analyze the orbital decay rates of PSR B1913+16 and PSR B1534+12 with a possible graviton mass as a parameter. The combined frequentist mass limit is at 90%CL.

[17] As of 2020, limits on dP/dt are now about 0.1% (see T. Damour, "Experimental tests of gravitational theory," in this *Review*).

[18] GOLDHABER 1974 establish this limit considering the binding of galactic clusters, corrected to Planck h_0 = 0.67.

References:

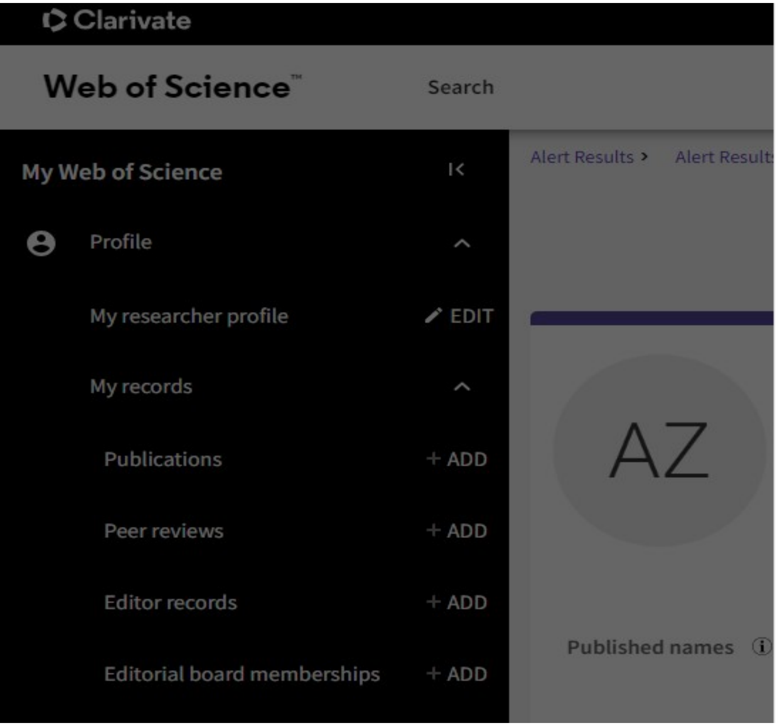
BERNUS	2020	PR D102 021501	Constraint on the Yukawa suppression of the Newtonian potential from the planetary ephemeris INPOP19a
SHAO	2020	PR D102 024069	New Graviton Mass Bound from Binary Pulsars
ABBOTT	2019	PR D100 104036	Tests of General Relativity with the Binary Black Hole Signals from the LIGO-Virgo Catalog GWTC-1
BERNUS	2019	PRL 123 161103	Constraining the mass of the graviton with the planetary ephemeris INPOP
MIAO	2019	PR D99 123015	Bounding the mass of graviton in a dynamic regime with binary pulsars
DESAI	2018	PL B778 325	Limit on graviton mass from galaxy cluster Abell 1689
GUPTA	2018	ANP 399 85	Limit on graviton mass using stacked galaxy cluster catalogs from SPT-SZ, Planck-SZ and SDSS-redMaPPer
RANA	2018	PL B781 220	Bounds on graviton mass using weak lensing and SZ effect in galaxy clusters
WILL	2018	CQG 35 17LT01	Solar system versus gravitational-wave bounds on the graviton mass
ABBOTT	2017	PRL 118 221101	GW170104: Observation of a 50-Solar-Mass Binary Black Hole Coalescence at Redshift 0.2
ABBOTT	2016	PRL 116 061102	Observation of Gravitational Waves from a Binary Black Hole Merger
ZAKHAROV	2016	JCAP 1605 045	Constraining the range of Yukawa gravity interaction from S2 star orbits II: Bounds on graviton mass
BRITO	2013	PR D88 023514	Massive Spin-2 Fields on Black Hole Spacetimes: Instability of the Schwarzschild and Kerr Solutions and Bounds on the Graviton Mass
GRUZINOV	2005	NAST 10 311	On the Graviton Mass
CHOUDHURY	2004	ASP 21 559	Probing Large Distance Higher Dimensional Gravity from Lensing Data
GERSHTEIN	2004	PAN 67 1596	Graviton Mass, Quintessence and Oscillatory Character of the Universe Evolution
FINN	2002	PR D65 044022	Bounding the Mass of the Graviton using Binary Pulsar Observations
TALMADGE	1988	PRL 61 1159	Model Independent Constraints on Possible Modifications of Newtonian Gravity
GOLDHABER	1974	PR D9 1119	Mass of the Graviton
HARE	1973	CJP 51 431	Mass of the Graviton

About citations

L. B. Okun said to young colleagues: “You have to prove that your studies are known in the world. Let me know a number of citations at your papers”.

A few year ago at ITEP seminar, a ITEP researcher informed people that a Nobel prize winner quoted his paper (and it was like a small sensation that Nobel prize winners knew papers from researchers of our Institute), and I decided to take a look how many Nobel prize winners quoted our paper and recognized that V. L. Ginzburg, S. Weinberg, G. Smoot, A. Ghez and her co-authors, R. Genzel and his co-authors. In particular, V. L. Ginzburg quoted our paper in his last reviews on the most interesting problems of physics and astrophysics.

I counted more than 30 citations on our paper from A. Ghez and R. Genzel groups in their papers on trajectories of bright stars near the GC.


Clarivate
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Publications
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Editor records
+ ADD
Editorial board memberships
+ ADD
AZ
Published names

In a recent paper GRAVITY collaboration quoted 8 our papers

A&A, 698, L15 (2025)
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Astronomy & Astrophysics

Letter to the Editor

Exploring the presence of a fifth force at the Galactic Center

GRAVITY Collaboration*: K. Abd El Dayem[1], R. Abuter[4], N. Aimar[10,7], P. Amaro Seoane[14,2,18], A. Amorim[8,7], J. P. Berger[3,4], H. Bonnet[4], G. Bourdarot[2], W. Brandner[5], V. Cardoso[7,15], Y. Clénet[1], R. Davies[2], P. T. de Zeeuw[19], A. Drescher[2], A. Eckart[6,13], F. Eisenhauer[2,17], H. Feuchtgruber[2], G. Finger[2], N. M. Förster Schreiber[2], A. Foschi[1,2,**], P. Garcia[10,7], E. Gendron[1], R. Genzel[2,11], S. Gillessen[2], M. Hartl[2], X. Haubois[9], F. Haussmann[2], T. Henning[5], S. Hippler[5], M. Horrobin[6], L. Jochum[9], L. Jocou[3], A. Kaufer[9], P. Kervella[1], S. Lacour[1,4], V. Lapeyrère[1], J.-B. Le Bouquin[3], P. Léna[1], D. Lutz[2], F. Mang[2], N. More[2], J. Osorno[1], T. Ott[2], T. Paumard[1], K. Perraut[3], G. Perrin[1], S. Rabien[2], D. C. Ribeiro[2], M. Sadun Bordoni[2], S. Scheithauer[5], J. Shangguan[20], T. Shimizu[2], J. Stadler[12,2], O. Straub[2,16], C. Straubmeier[6], E. Sturm[2], L. J. Tacconi[2], I. Urso[1], F. Vincent[1], S. D. von Fellenberg[13,2], E. Wieprecht[2], and J. Woillez[4]

(Affiliations can be found after the references)

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ABSTRACT

Aims. We investigate the presence of a Yukawa-like correction to Newtonian gravity at the Galactic Center, leading to a new upper limit on the intensity of such a correction.
Methods. We performed a Markov chain Monte Carlo (MCMC) analysis using the astrometric and spectroscopic data of star S2 collected at the Very Large Telescope by GRAVITY, NACO, and SINFONI instruments, covering the period from 1992 to 2022.
Results. The precision of the GRAVITY instrument allows us to derive the most stringent upper limit at the Galactic Center for the intensity of the Yukawa contribution ($\propto \alpha e^{-\lambda r}$) of $|\alpha| < 0.003$ for a scale length of $\lambda = 3 \cdot 10^{13}$ m (~ 200 AU). This is an improvement on all estimates obtained in previous works by roughly one order of magnitude.

Key words. gravitation – celestial mechanics – Galaxy: center

1. Introduction

General relativity (GR) is the most widely recognized theory of gravity today. Its predictions have been extensively tested on Solar System scales and using gravitational waves emission by black holes (BHs) and binary pulsars (Will 2014, 2018a; Nitz et al. 2021). Until now, no significant deviation from GR

One way to address these inconsistencies between theory and experiments is to directly modify GR, giving rise to a plethora of possible extended theories of gravity (ETG). In particular, a Yukawa-like interaction emerges quite naturally in the weak field limit of several ETGs; for instance, scalar-tensor-vector theories (Moffat 2006), massive gravity theories (Visser 1998; Hinterbichler 2012), theo-

Ciência e a Tecnologia), to ESO and the Paranal staff, and to the many scientific and technical staff members in our institutions, who helped to make NACO, SINFONI, and GRAVITY a reality. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 101007855. We acknowledge the financial support provided by FCT/Portugal through grants 2022.01324.PTDC, PTDC/FIS-AST/7002/2020, UIDB/00099/2020 and UIDB/04459/2020. J.S. acknowledge the National Science Foundation of China (12233001) and the National Key R&D Program of China (2022YFF0503401).

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modification $\mu(a)$ of Kepler's third law:

$$\frac{a^3}{T^2} = \frac{M_\odot(1+\mu(a))}{4(2\pi)^3 M_{\rm Pl}^2}, \tag{3.10}$$

where a and T are the semi-major axis and the period of the planet's orbit. In GR, $\mu = 0$, while in models of modified gravity, μ can depart from unity in some regime and acquire a non-trivial radius dependence, $\mu = \mu(a)$. Comparing the ratio a^3/T^2 of various planets provides a powerful way to test GR with the best bounds given by comparison of the ratio for the Earth and the Moon (Talmadge *et al.*, 1988).

Besides modifying Kepler's third law and including fifth force effects, modifications of the standard Newtonian potential can lead to an additional precession beyond that expected from GR and the fifth forces. This implies that even theories that do not involve any additional degrees of freedom or carry no fifth force effects can still lead to an additional advance of the perihelion on top of GR's expected precession. These effects are typically less constrained than the corrections to Kepler's third law but should still be under control.

3.4.5 *Black holes and stellar solutions*

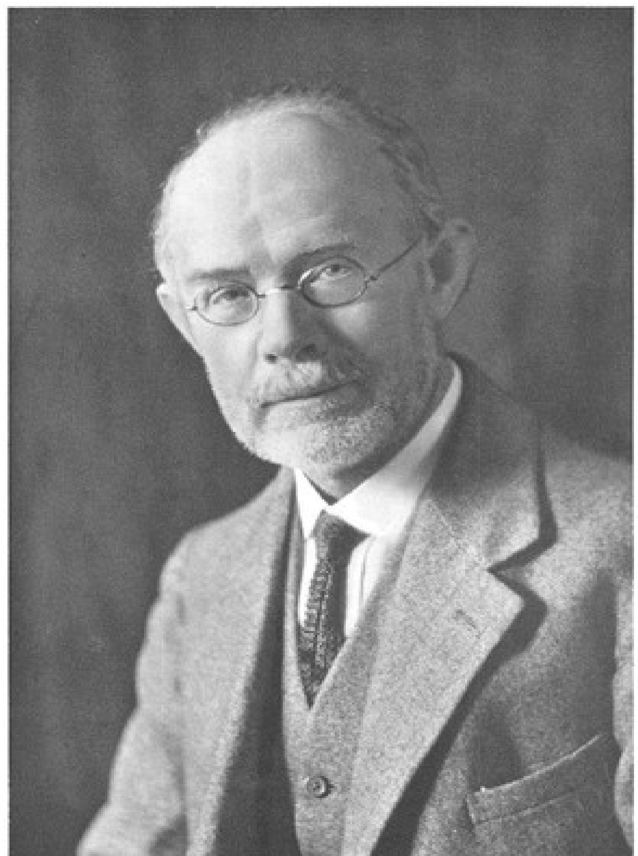
All of the constraints on planetary orbits within the solar system are also applicable to the orbits of stars in the vicinity of black holes, including Sagittarius A*, with S2-like stars orbiting the black hole within distances comparable to that in the solar system as observed by the **W.M. KECK observatory** (Eckart and Genzel, 1996; Ghez *et al.*, 2005a,b; Gillessen *et al.*, 2009; Meyer *et al.*, 2012) leading to competitive tests of modified gravity (Borka *et al.*, 2012, 2013; Zakharov *et al.*, 2016).

In parallel, the modification of the black hole solution itself in theories of modified gravity can be matched against its shadow as observed by the **Event Horizon Telescope** (Akiyama *et al.*, 2022a) and has already been used to constrain models of modified gravity (Akiyama *et al.*, 2022b; Psaltis *et al.*, 2020; Shaikh, 2023; Vagnozzi *et al.*, 2022; Zakharov, 2022). The potential presence of hair, superradiance and other effects modifying the black hole structure near the horizon could provide competitive tests of modified gravity in the future.

In addition, modifications of gravity can affect the **sequence of stars** and structure of other astrophysical systems. The presence of additional degrees of freedom that often go along with modified gravity, when equilibrated in a stellar core, can drive new stellar instabilities which would manifest in **mass gaps in black hole populations** (see Straight *et al.*, 2020 for an example). Modified gravity effects can also change the equilibrium structure of main sequence stars, modifying the relation between their mass and luminosity (stars are typically brighter in theories of gravity involving a Chameleon-like screened scalar field like in $f(R)$), an effect which is then reflected in their radii and ages (Davis *et al.*, 2012). Reviews on other astrophysical tests of modified gravity can be found in Alves Batista *et al.* (2021); Baker *et al.* (2021); Sakstein (2020).

Shadow reconstructions for M87* and Sgr A* are based on three pillars: Synchrotron radiation, VLBI concept, GR in a strong gravitational field

Synchrotron radiation predicted by George A. Schott



G. A. Schott

ELECTROMAGNETIC RADIATION

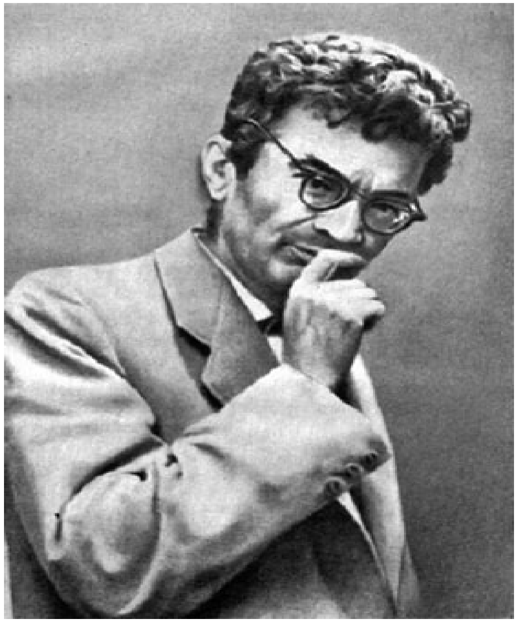
AND THE MECHANICAL REACTIONS ARISING FROM IT

BEING AN ADAMS PRIZE ESSAY IN THE UNIVERSITY OF CAMBRIDGE

by

G. A. SCHOTT, B.A., D.Sc.
Professor of Applied Mathematics in the University College of Wales, Aberystwyth
Formerly Scholar of Trinity College, Cambridge

Cambridge:
at the University Press
1912



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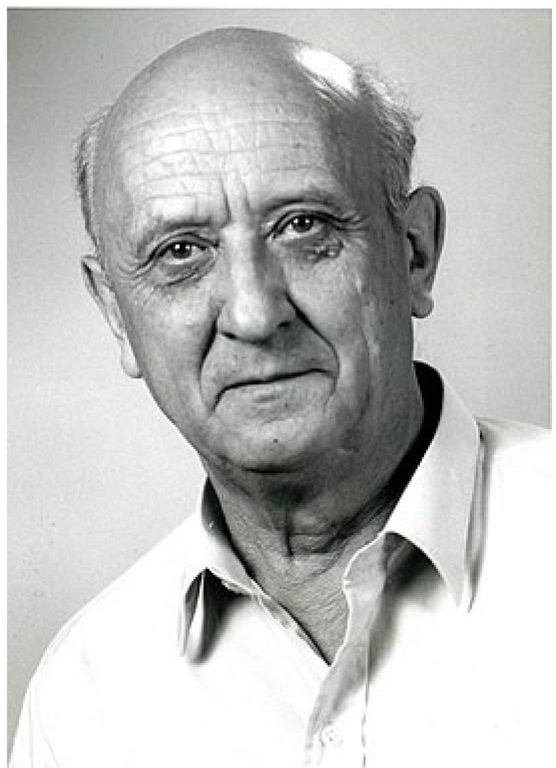
In 1950 D. Ivanenko, A. A. Sokolov and I. Pomeranchuk were awarded the State prize of the second grade

Academician Lev Andreevich Artsimovich (the founder of the Atomic physics chair at the Physical department of MSU, Academician secretary of the General Physics and Astronomy division (before Academician secretary of the Mathematics and Physics Division) of the Soviet Academy of Sciences, the chairman of the National committee of physicists)

Synchrotron radiation plays a key role in many astrophysical objects (including BH's and pulsars (Crab Nebula)) . In 1946 they predicted emission in radio band from solar corona. In May 1947 they participated in Brazil expedition

The Soviet expedition in Brazil for solar eclipse observations in 20 May 1947 where S. E. Khaikin and B. M. Chikhachev discovered radio emission from solar corona during the solar eclipse aboard the “Griboedov” ship

The idea of VLBI observation was introduced by L. I. Matveenko (1929—2019) in 1960s and it was realized in Soviet – US joint radio observations in 1970s. Matveenko proposed also a project of a ground – space interferometer. This idea was realized later by Japanese (HALCA, VSOP, 1997) and Russian Astronomers (Radioastron, 2011) .



For about 20 years we declared that black holes are specific metrics for theorists while black holes are dark spots (shadows) for observers and we reported these ideas in many institutes located in different places over the world (Russia, Serbia, China, Bulgaria, Switzerland, Italy, Greece, Germany, USA, UK, India, Pakistan, Australia, Spain, France). These ideas were also reported at EHT meetings.

International Journal of Modern Physics D | Online Ready

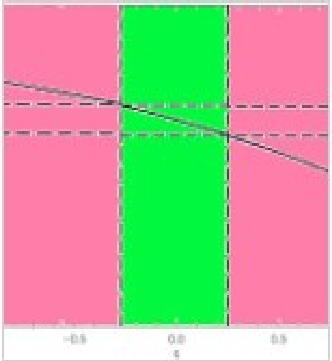
Shadows near supermassive black holes: From a theoretical concept to GR test

Alexander F. Zakharov

https://doi.org/10.1142/S0218271823400047

Abstract

General relativity (GR) passed many astronomical tests but in majority of them GR predictions have been tested in a weak gravitational field approximation. Around 50 years ago a shadow was introduced by Bardeen as a purely theoretical concept but due to an enormous progress in observational and computational facilities this theoretical prediction has been confirmed and the most solid argument for an existence of supermassive black holes in Sgr A* and M87* has been obtained.



Shadows near supermassive black holes: From a theoretical concept to GR test

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International Journal of Modern Physics D

Alexander F. Zakharov

At the initial stage of development of GR and quantum mechanics gedanken (thought) experiments were very popular in a discussion of specific features of new theories. To discuss observations signatured of black holes J. M. Bardeen considered features of an existence of bright screen which is located behind a Kerr black hole in the case of an observer is located in the equatorial plane. In these considerations it was assumed that photons emitted by a luminous screen do not interact with a matter around a black hole.

Clearly, this gedanken experiment looked rather artificial since first, there are no luminous screens behind astrophysical black holes, second, masses of black holes were estimated not precisely and a majority of astrophysical black holes were black holes with stellar masses but even now shadows around these black holes are too small to be detected, third, it was not clear how to detect a darkness or to distinguish it from a faintness.

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THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Relativistic orbits of S2 star in the presence of scalar field

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Abstract The general theory of relativity predicts the relativistic effect in the orbital motions of S-stars which are orbiting around our Milky-way Galactic Center. The post-Newtonian or higher-order approximated Schwarzschild black hole models have been used by GRAVITY and UCLA Galactic Center groups to carefully investigate the S2 star's periastron precession. In this paper, we investigate the scalar field effect on the orbital dynamics of S2 star. Hence, we consider a spacetime, namely Janis-Newman-Winicour (JNW) spacetime which is seeded by a minimally coupled, mass-less scalar field. The novel feature of this spacetime is that one can retain the Schwarzschild spacetime from JNW spacetime considering zero scalar charge. We constrain the scalar charge of JNW spacetime by best fitting the astrometric data of S2 star using the Monte-Carlo–Markov-Chain (MCMC) technique assuming the charge to be positive. Our best-fitted result implies that similar to the Schwarzschild black hole spacetime, the JNW naked singularity spacetime with an appropriate scalar charge also offers a satisfactory fitting to the observed data for S2 star. Therefore, the JNW naked singularity could be a contender for explaining the nature of Sgr A* through the orbital motions of the S2 star.

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1 Introduction

The idea of reconstructing the shadow of a black hole in the Galactic Center using global interferometers operating in the millimeter wavelength was initially suggested in [1]. Recently, the Event Horizon Telescope collaboration has announced a major breakthrough in the imaging of an ultra-compact object at the centre of our Galaxy [2–7]. A bright emission ring around a core brightness depression in VLBI horizon-scale images of Sgr A*, with the latter linked to the shadow of black hole. The shadow boundary of the Sgr A* marks the visual image of the photon region and differentiates capture orbits from scattering orbits on the plane of a distant observer. The radius of the bright ring can be used as an approximation for the black hole shadow radius under specific conditions and after proper calibration, with little reliance on the details of the surrounding accretion flux. While there is strong evidence that there is a high concentration of mass in the center of our Milky Way Galaxy, the question of whether or not it is a black hole is still open. They have considered various alternatives such as naked singularities and regular black holes. They favorably acknowledge that the naked singularity with a photon sphere Joshi-Malafarina-Narayan (JMN-1) naked singularity could be the best black hole mimicker [7]. The central object and its nature remain mysterious. This is because just like a black hole case, the JMN-1 naked singularity would create a similar shadow, and therefore it is very difficult to distinguish between the two. Therefore, in this paper, we study the relativistic orbits of stars that are orbiting around our own Galactic Center.

Published online: 06 February 2024

AFZ et al., NA (2005): “In our old paper https://ui.adsabs.harvard.edu/.../2005NewA...10.../abstract

we wrote at the end "In spite of the difficulties of measuring the shapes of images near black holes is so attractive challenge to look at the ‘‘faces’’ of black holes because namely the mirages outline the ‘‘faces’’ and correspond to fully general relativistic description of a region near black hole horizon without any assumption about a specific model for astrophysical processes around black holes (of course we assume that there are sources illuminating black hole surroundings). No doubt that the rapid growth of observational facilities will give a chance to measure the mirage shapes using not only RADIOASTRON facilities but using also other instruments and spectral bands (for example, X-ray interferometer MAXIM (White, 2000; Cash et al., 2000) or sub-mm VLBI array (Miyoshi, 2004)).

Astro Space Centre of Lebedev Physics Institute proposed except the RADIOASTRON mission and developed also space based interferometers (Millimetron and Sub-millimetron) for future observations in mm and sub-mm bands. These instruments could be used for the determination of shadow shapes.

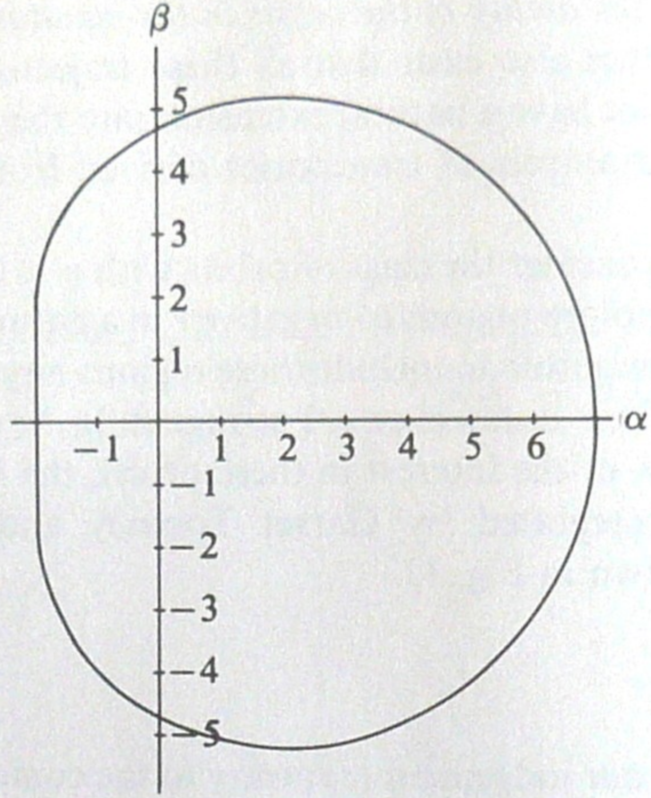


FIG. 38. The apparent shape of an extreme ($a = M$) Kerr black-hole as seen by a distant observer in the equatorial plane, if the black hole is in front of a source of illumination with an angular size larger than that of the black hole. The unit of length along the coordinate axes α and β (defined in equation (241) is M.

black hole from infinity, the apparent shape will be determined by

$$(\alpha, \beta) = [\xi, \sqrt{\eta}(\xi)]. \tag{242}$$

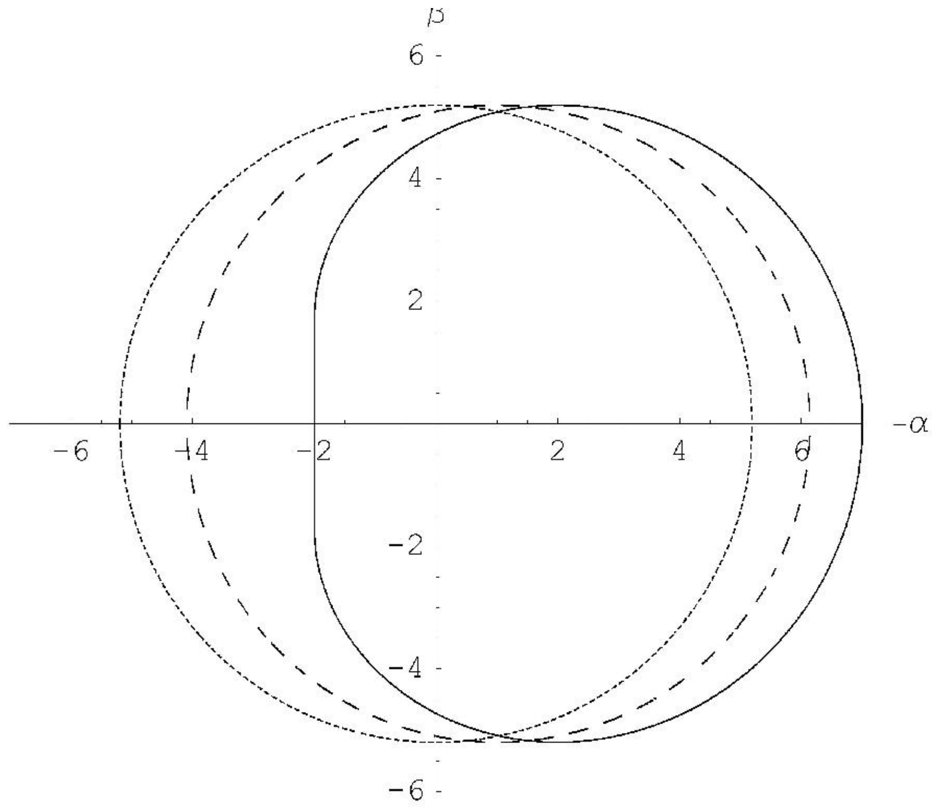


Fig. 2. Mirages around black hole for equatorial position of distant observer and different spin parameters. The solid line, the dashed line and the dotted line correspond to $a = 1, a = 0.5, a = 0$ correspondingly

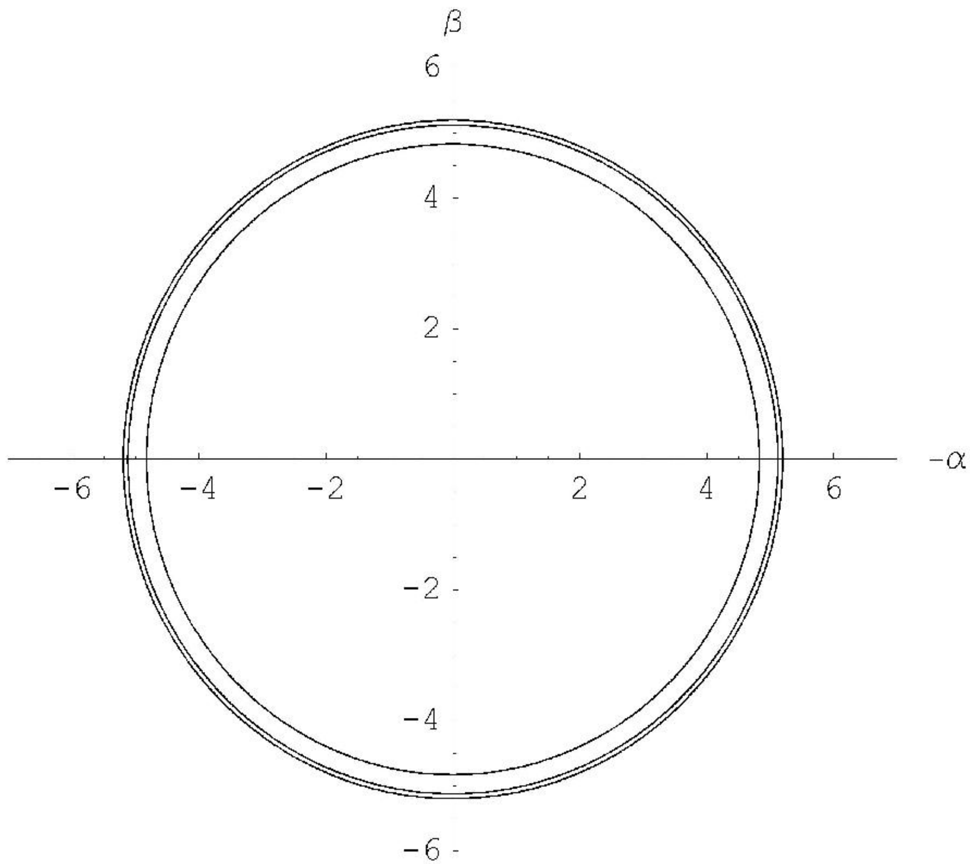


Fig. 3. Mirages around a black hole for the polar axis position of distant observer and different spin parameters ($a = 0, a = 0.5, a = 1$). Smaller radii correspond to greater spin parameters.

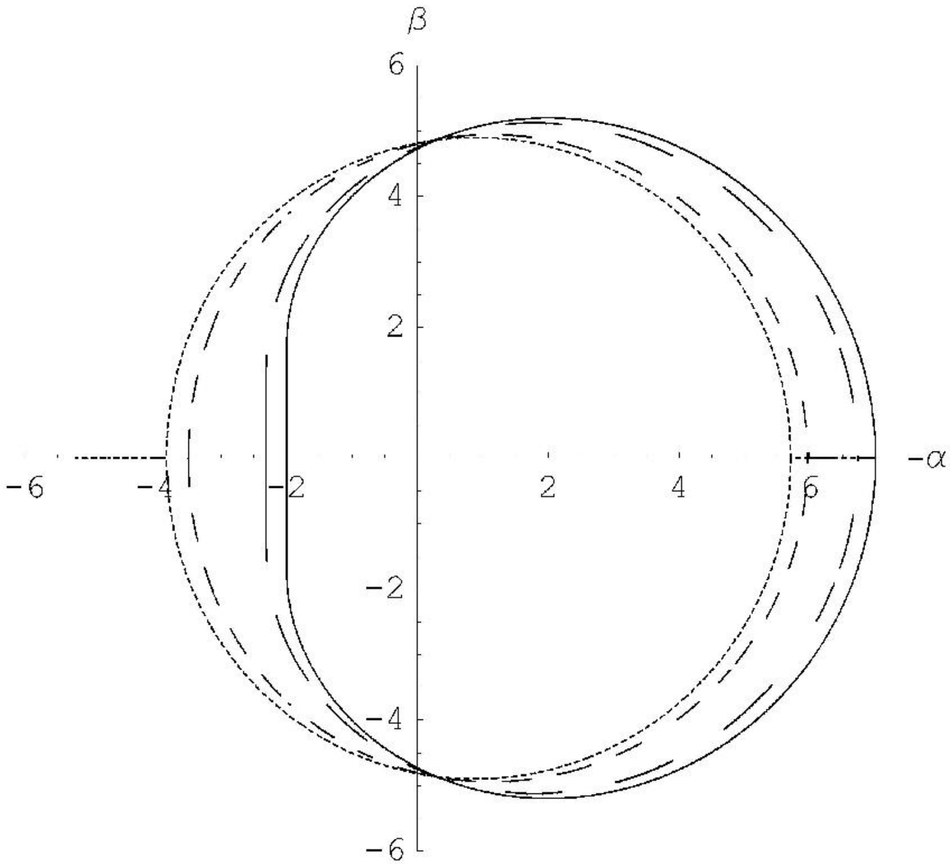


Fig. 5. Mirages around black hole for different angular positions of a distant observer and the spin $a = 1$. Solid, long dashed, short dashed and dotted lines correspond to $\theta_0 = \pi/2, \pi/3, \pi/6$ and $\pi/8$, respectively.

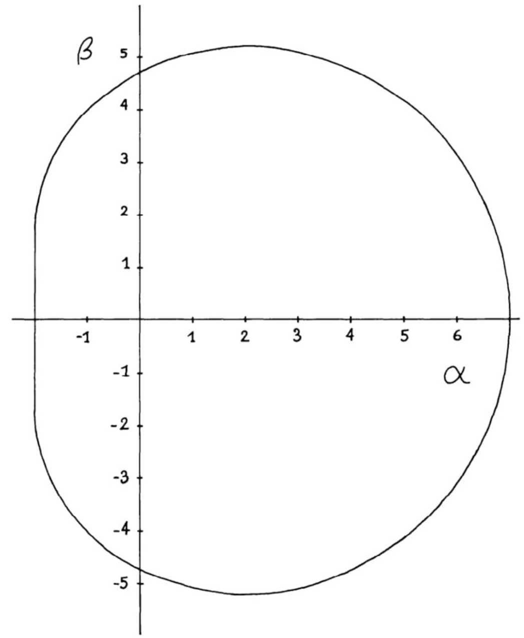


Figure 6. The apparent shape of an extreme ($a = m$) Kerr black hole as seen by a distant observer in the equatorial plane, if the black hole is in front of a source of illumination with an angular size larger than that of the black hole.

is largest there and because of the gravitational focusing effects associated with the bending of the rays toward the equatorial plane. Note that the radiation comes out along the flat portion of the apparent boundary of the extreme black hole as plotted in Figure 6.

D. Geometrical Optics

A detailed calculation of the brightness distribution coming from a source near a Kerr black hole requires more of geometrical optics than the calculation of photon trajectories. I will now review some techniques which are useful in making astrophysical calculations in connection with black holes.

The fundamental principle can be expressed as the conservation of photon density in phase space along each photon trajectory. A phase space element $d^3x\, d^3p$, the product of a proper spatial volume element and a physical momentum-space volume element in a local observer's frame of reference, is a Lorentz invariant, so the particular choice of local observer is arbitrary. The density $N(x^a, p^{(\beta)})$ is defined

James Maxwell Bardeen passed away on June 20, 2022

Left: William and John (left) Bardeen, two brothers. ***Right:*** John Bardeen with his wife, Jane Maxwell
Image courtesy: “True Genius” by Hoddenson and Daitch [4]

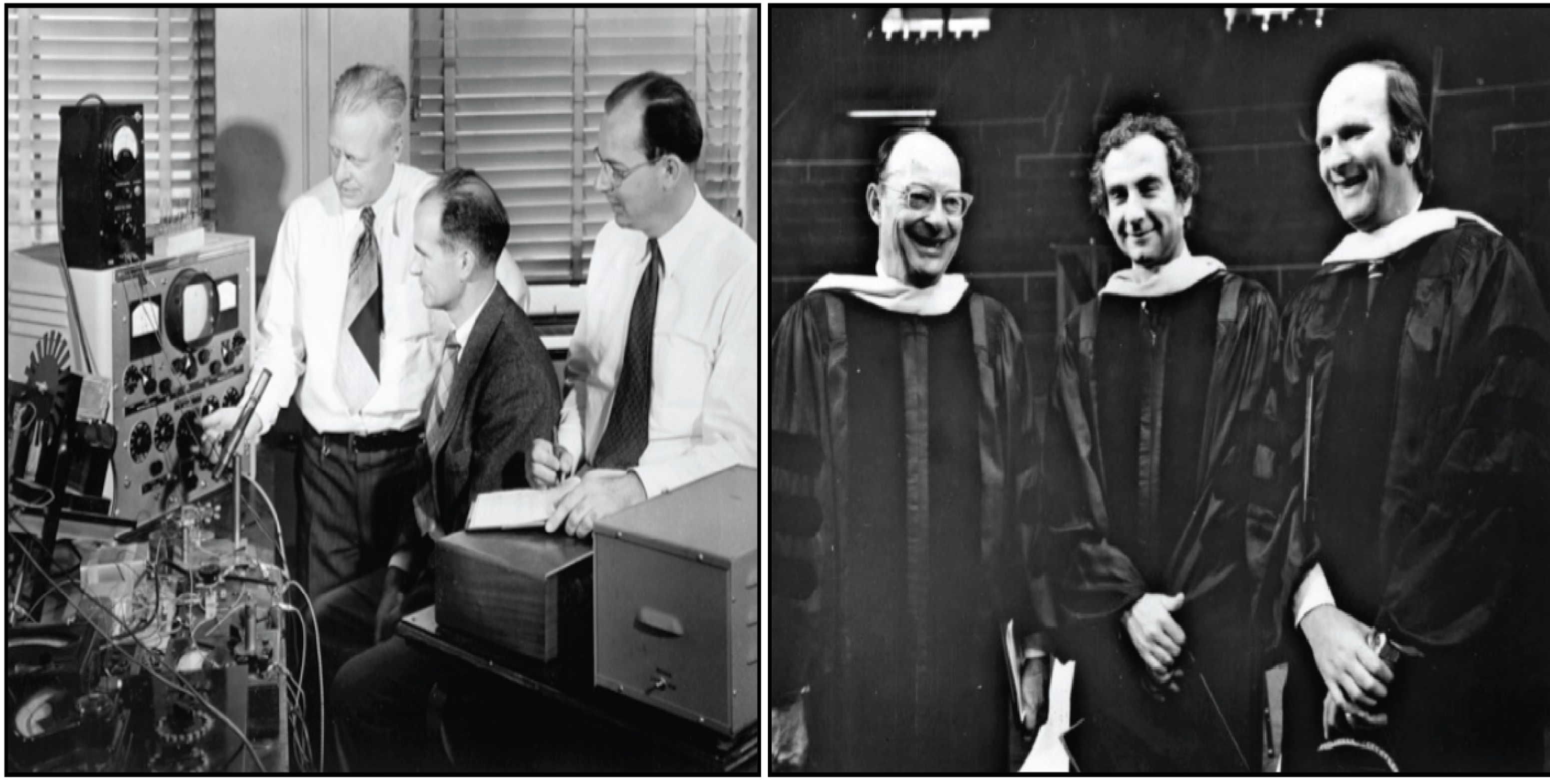
John Bardeen (1908 -1991), the father of J. M. Bardeen. E. Wigner was J. Bardeen's supervisor.

At the Nobel Prize ceremony in Stockholm, Brattain and Shockley received their awards that night from King Gustaf VI Adolf. Bardeen brought only one of his three children to the Nobel Prize ceremony. King Gustav chided Bardeen because of this, and Bardeen assured the King that the next time he would bring all his children to the ceremony. He kept his promise. Bardeen brought his three children to the Nobel Prize ceremony in Stockholm in 1972.

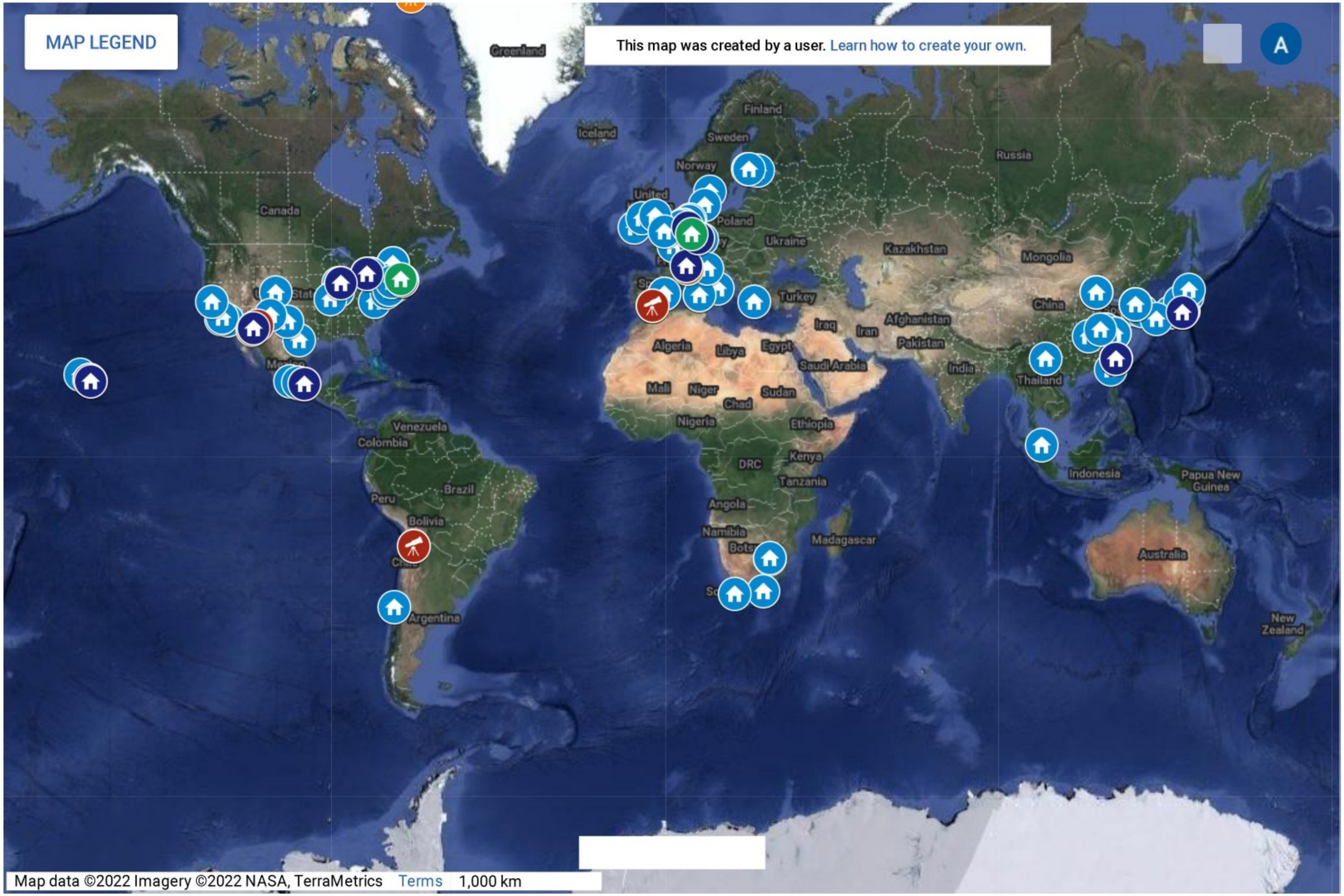
1956: John Bardeen is the only scientist to receive 2 Nobel Prizes in physics. While receiving his first, King Gustav scolded him for only bringing one of his 3 children to such an important occasion. He replied, "I'll bring them all for the next time." He did.

Image

Bardeen and Brattain proposed an alternative design of amplifier based on germanium, instead of the previously popular elemental silicon. It was December 16, 1947, the day modern transistor was born, marking a revolution in the field of communications.



Left: Brattain, Shockley and Bardeen (L to R) in the Bell Labs in 1948. ***Right:*** Bardeen, Cooper and Schrieffer (L to R) in 1974. *Image courtesy:* “True Genius” by Hoddenson and Daitch [4]


MAP LEGEND
This map was created by a user. Learn how to create your own.
A
Greenland
Iceland
Finland
Sweden
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Russia
Canada
Poland
Ukraine
Kazakhstan
Mongolia
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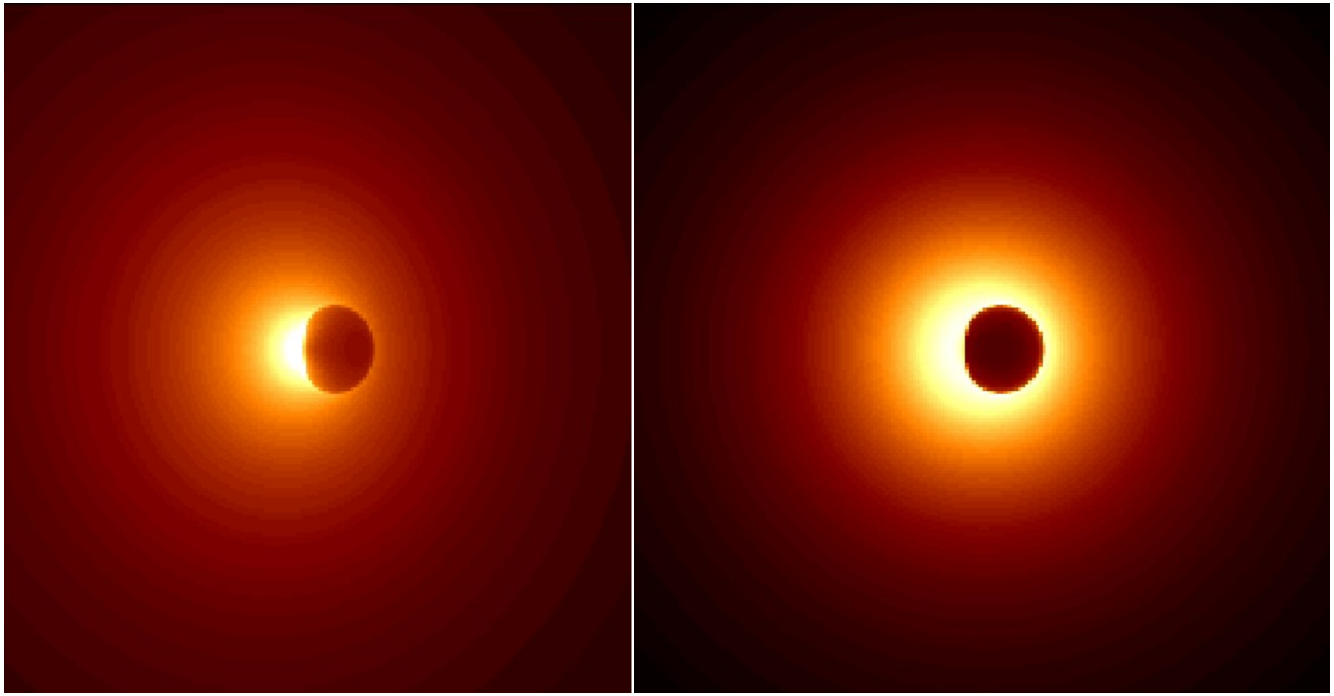
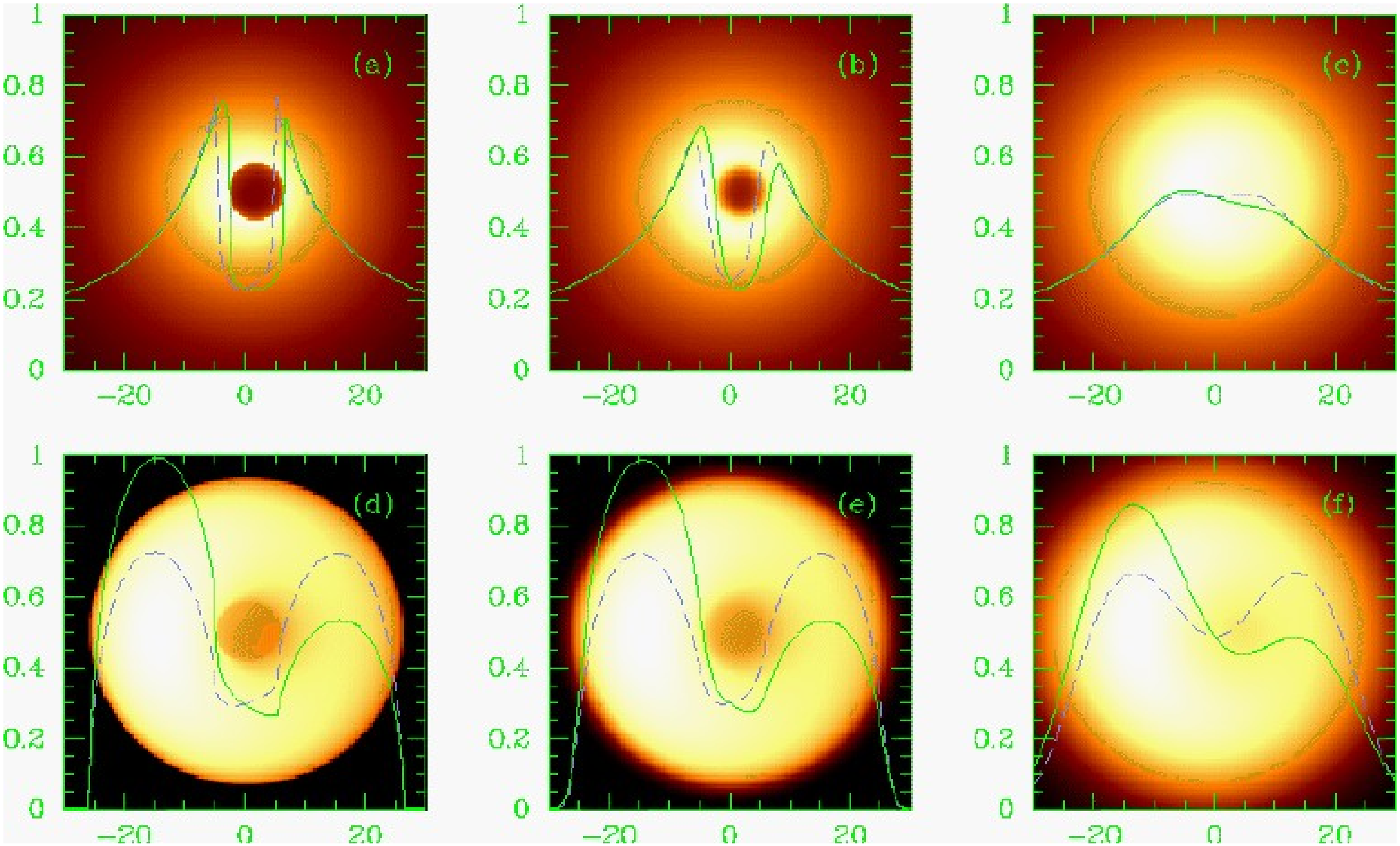
Iraq
Iran
Afghanistan
Pakistan
Algeria
Libya
Egypt
Saudi Arabia
India
Thailand
Mali
Niger
Sudan
Chad
Nigeria
Ethiopia
Venezuela
Colombia
Kenya
DRC
Tanzania
Indonesia
Papua New Guinea
Brazil
Peru
Bolivia
Angola
Namibia
Madagascar
Australia
Argentina
New Zealand
Map data ©2022 Imagery ©2022 NASA, TerraMetrics Terms 1,000 km

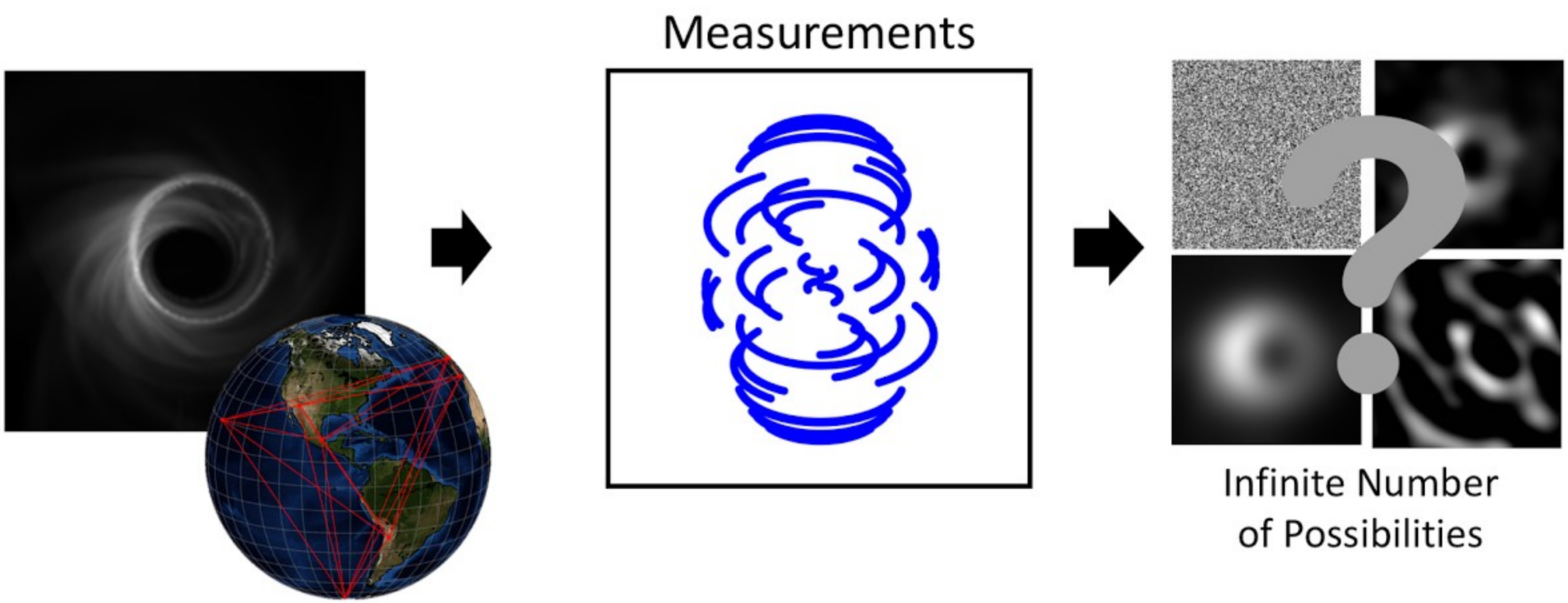
Shadows from Melia



Falcke, Melia, Agol



EHT team: “Similarly, for the EHT, the data we take only tells us only a piece of the story, as there are an infinite number of possible images that are perfectly consistent with the data we measure. But not all images are created equal— some look more like what we think of as images than others. To chose the best image, we essentially take all of the infinite images that explain our telescope measurements, and rank them by how reasonable they look. We then choose the image (or set of images) that looks most reasonable. “



Constraints on black-hole charges with the 2017 EHT observations of M87*

Prashant Kocherlakota,[1] Luciano Rezzolla,[1–3] Heino Falcke,[4] Christian M. Fromm,[5,6,1] Michael Kramer,[7]
Yosuke Mizuno,[8,9] Antonios Nathanail,[9,10] Héctor Olivares,[4] Ziri Younsi,[11,9] Kazunori Akiyama,[12,13,5] Antxon Alberdi,[14]
Walter Alef,[7] Juan Carlos Algaba,[15] Richard Anantua,[5,6,16] Keiichi Asada,[17] Rebecca Azulay,[18,19,7] Anne-Kathrin Baczko,[7]
David Ball,[20] Mislav Baloković,[5,6] John Barrett,[12] Bradford A. Benson,[21,22] Dan Bintley,[23] Lindy Blackburn,[5,6]
Raymond Blundell,[6] Wilfred Boland,[24] Katherine L. Bouman,[5,6,25] Geoffrey C. Bower,[26] Hope Boyce,[27,28]
Michael Bremer,[29] Christiaan D. Brinkerink,[4] Roger Brissenden,[5,6] Silke Britzen,[7] Avery E. Broderick,[30–32]
Dominique Broguiere,[29] Thomas Bronzwaer,[4] Do-Young Byun,[33,34] John E. Carlstrom,[35,22,36,37] Andrew Chael,[38,39]
Chi-kwan Chan,[20,40] Shami Chatterjee,[41] Koushik Chatterjee,[42] Ming-Tang Chen,[26] Yongjun Chen (陈永军),[43,44]
Paul M. Chesler,[5] Ilje Cho,[33,34] Pierre Christian,[45] John E. Conway,[46] James M. Cordes,[41] Thomas M. Crawford,[22,35]
Geoffrey B. Crew,[12] Alejandro Cruz-Osorio,[9] Yuzhu Cui,[47,48] Jordy Davelaar,[49,16,4] Mariafelicia De Laurentis,[50,9,51]
Roger Deane,[52–54] Jessica Dempsey,[23] Gregory Desvignes,[55] Sheperd S. Doeleman,[5,6] Ralph P. Eatough,[56,7]
Joseph Farah,[6,5,57] Vincent L. Fish,[12] Ed Fomalont,[58] Raquel Fraga-Encinas,[4] Per Friberg,[23] H. Alyson Ford,[59]
Antonio Fuentes,[14] Peter Galison,[5,60,61] Charles F. Gammie,[62,63] Roberto García,[29] Olivier Gentaz,[29] Boris Georgiev,[31,32]
Ciriaco Goddi,[4,64] Roman Gold,[65,30] José L. Gómez,[14] Arturo I. Gómez-Ruiz,[66,67] Minfeng Gu (顾敏峰),[43,68]
Mark Gurwell,[6] Kazuhiro Hada,[47,48] Daryl Haggard,[27,28] Michael H. Hecht,[12] Ronald Hesper,[69] Luis C. Ho (何子山),[70,71]
Paul Ho,[17] Mareki Honma,[47,48,72] Chih-Wei L. Huang,[17] Lei Huang (黄磊),[43,68] David H. Hughes,[66] Shiro Ikeda,[13,73–75]
Makoto Inoue,[17] Sara Issaoun,[4] David J. James,[5,6] Buell T. Jannuzi,[20] Michael Janssen,[7] Britton Jeter,[31,32]
Wu Jiang (江悟),[43] Alejandra Jimenez-Rosales,[4] Michael D. Johnson,[5,6] Svetlana Jorstad,[76,77] Taehyun Jung,[33,34]
Mansour Karami,[30,31] Ramesh Karuppusamy,[7] Tomohisa Kawashima,[78] Garrett K. Keating,[6] Mark Kettenis,[79]
Dong-Jin Kim,[7] Jae-Young Kim,[33,7] Jongsoo Kim,[33] Junhan Kim,[20,25] Motoki Kino,[13,80] Jun Yi Koay,[17] Yutaro Kofuji,[47,72]
Patrick M. Koch,[17] Shoko Koyama,[17] Carsten Kramer,[29] Thomas P. Krichbaum,[7] Cheng-Yu Kuo,[81,17] Tod R. Lauer,[82]
Sang-Sung Lee,[33] Aviad Levis,[25] Yan-Rong Li (李彦荣),[83] Zhiyuan Li (李志远),[84,85] Michael Lindqvist,[46] Rocco Lico,[14,7]
Greg Lindahl,[6] Jun Liu (刘俊),[7] Kuo Liu,[7] Elisabetta Liuzzo,[86] Wen-Ping Lo,[17,87] Andrei P. Lobanov,[7] Laurent Loinard,[88,89]
Colin Lonsdale,[12] Ru-Sen Lu (路如森),[43,44,7] Nicholas R. MacDonald,[7] Jirong Mao (毛基荣),[90–92] Nicola Marchili,[86,7]
Sera Markoff,[42,93] Daniel P. Marrone,[20] Alan P. Marscher,[76] Iván Martí-Vidal,[18,19] Satoki Matsushita,[17]
Lynn D. Matthews,[12] Lia Medeiros,[94,20] Karl M. Menten,[7] Izumi Mizuno,[23] James M. Moran,[5,6] Kotaro Moriyama,[12,47]
Monika Moscibrodzka,[4] Cornelia Müller,[7,4] Gibwa Musoke,[42,4] Alejandro Mus Mejías,[18,19] Hiroshi Nagai,[13,48]
Neil M. Nagar,[95] Masanori Nakamura,[96,17] Ramesh Narayan,[5,6] Gopal Narayanan,[97] Iniyan Natarajan,[54,52,98]
Joseph Neilsen,[99] Roberto Neri,[29] Chunchong Ni,[31,32] Aristeidis Noutsos,[7] Michael A. Nowak,[100] Hiroki Okino,[47,72]
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Ue-Li Pen,[30,101–103] Dominic W. Pesce,[5,6] Vincent Piétu,[29] Richard Plambeck,[104] Aleksandar PopStefanija,[97]
Oliver Porth,[42,9] Felix M. Pötzl,[7] Ben Prather,[62] Jorge A. Preciado-López,[30] Dimitrios Psaltis,[20] Hung-Yi Pu,[105,17,30]
Venkatessh Ramakrishnan,[95] Ramprasad Rao,[26] Mark G. Rawlings,[23] Alexander W. Raymond,[5,6] Angelo Ricarte,[5,6]
Bart Ripperda,[106,16] Freek Roelofs,[4] Alan Rogers,[12] Eduardo Ros,[7] Mel Rose,[20] Arash Roshanineshat,[20] Helge Rottmann,[7]
Alan L. Roy,[7] Chet Ruszczyk,[12] Kazi L. J. Rygl,[86] Salvador Sánchez,[107] David Sánchez-Arguelles,[66,67] Mahito Sasada,[47,108]
Tuomas Savolainen,[109,110,7] F. Peter Schloerb,[97] Karl-Friedrich Schuster,[29] Lijing Shao,[7,71] Zhiqiang Shen (沈志强),[43,44]
Des Small,[79] Bong Won Sohn,[33,34,111] Jason SooHoo,[12] He Sun (孙赫),[25] Fumie Tazaki,[47] Alexandra J. Tetarenko,[112]
Paul Tiede,[31,32] Remo P. J. Tilanus,[4,64,113,20] Michael Titus,[12] Kenji Toma,[114,115] Pablo Torne,[7,107] Tyler Trent,[20]
Efthalia Traianou,[7] Sascha Trippe,[116] Ilse van Bemmel,[79] Huib Jan van Langevelde,[79,117] Daniel R. van Rossum,[4]
Jan Wagner,[7] Derek Ward-Thompson,[118] John Wardle,[119] Jonathan Weintroub,[5,6] Norbert Wex,[7] Robert Wharton,[7]
Maciek Wielgus,[5,6] George N. Wong,[62] Qingwen Wu (吴庆文),[120] Doosoo Yoon,[42] André Young,[4] Ken Young,[6]
Feng Yuan (袁峰),[43,68,121] Ye-Fei Yuan (袁业飞),[122] J. Anton Zensus,[7] Guang-Yao Zhao,[14] and Shan-Shan Zhao[43]

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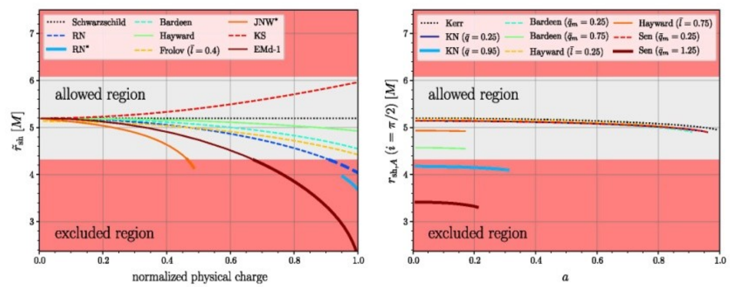


FIG. 2. Left: shadow radii $\tilde{r}_{sh}$ for various spherically symmetric black-hole solutions, as well as for the JNW and RN naked singularities (marked with an asterisk), as a function of the physical charge normalized to its maximum value. The gray/red shaded regions refer to the areas that are 1-σ consistent/inconsistent with the 2017 EHT observations and highlight that the latter set constraints on the physical charges (see also Fig. 3 for the EMd-2 black hole). Right: shadow areal radii $r_{sh,A}$ as a function of the dimensionless spin a for four families of black-hole solutions when viewed on the equatorial plane ($i = \pi/2$). Also in this case, the observations restrict the ranges of the physical charges of the Kerr-Newman and the Sen black holes (see also Fig. 3).

independent charges—can also produce shadow radii that are incompatible with the EHT observations; we will discuss this further below. The two EMd black-hole solutions (1 and 2) correspond to fundamentally different field contents, as discussed in [70].

We report in the right panel of Fig. 2 the shadow areal radius $r_{sh,A}$ for a number of stationary black holes, such as Kerr [72], Kerr-Newman (KN) [73], Sen [74], and the rotating versions of the Bardeen and Hayward black holes [75]. The data refers to an observer inclination angle of $i = \pi/2$, and we find that the variation in the shadow size with spin at higher inclinations (of up to $i = \pi/100$) is at most about 7.1% (for $i = \pi/2$, this is 5%); of course, at zero-spin the shadow size does not change with inclination. The shadow areal radii are shown as a function of the dimensionless spin of the black hole $a := J/M^2$, where J is its angular momentum, and for representative values of the additional parameters that characterize the solutions. Note that—similar to the angular momentum for a Kerr black hole—the role of an electric charge or the presence of a de Sitter core (as in the case of the Hayward black holes) is to reduce the apparent size of the shadow. Furthermore, on increasing the spin parameter, we recover the typical trend that the shadow becomes increasingly noncircular, as encoded, e.g., in the distortion parameter δ_{sh} defined in [57,83] (see Appendix). Also in this case, while the regular rotating Bardeen and Hayward solutions are compatible with the present constraints set by the 2017 EHT observations, the Kerr-Newman and Sen families of black holes can produce shadow areal radii that lie outside of the 1-σ region allowed by the observations.

To further explore the constraints on the excluded regions for the Einstein-Maxwell-dilaton 2 and the Sen black holes, we report in Fig. 3 the relevant ranges for these two solutions. The Einstein-Maxwell-dilaton 2 black holes are nonrotating but have two physical charges expressed by the coefficients $0 < \bar{q}_e < \sqrt{2}$ and $0 < \bar{q}_m < \sqrt{2}$, while the Sen black holes spin (a) and have an additional electromagnetic charge $\bar{q}_m$. Also in this case, the gray/red shaded regions refer to the areas that are consistent/inconsistent with the 2017 EHT observations. The figure shows rather easily that for these two black-hole families there are large

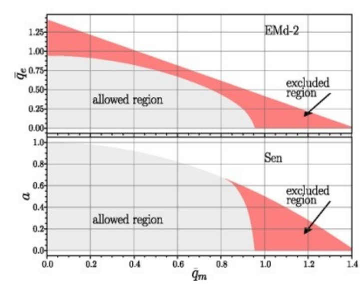
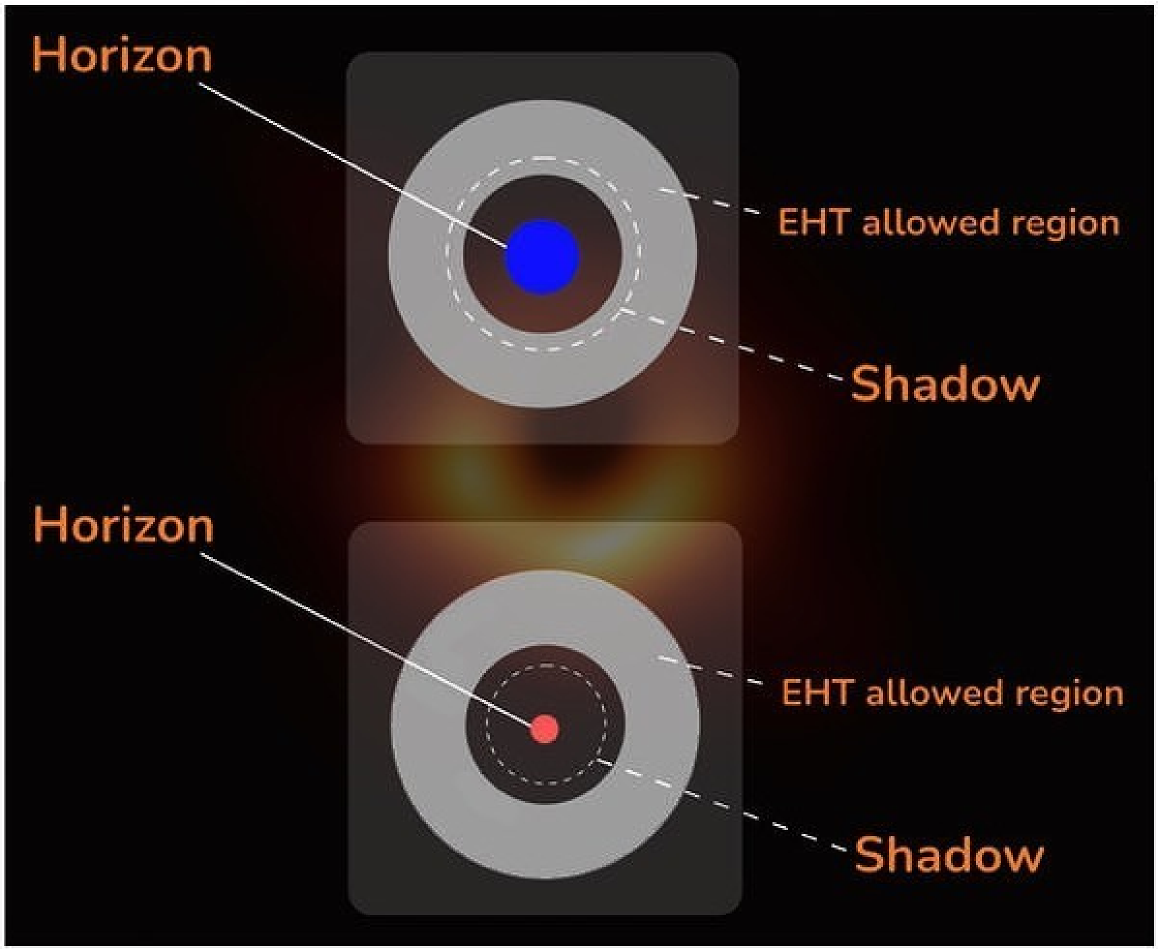


FIG. 3. Constraints set by the 2017 EHT observations on the nonrotating Einstein-Maxwell-dilaton 2 and on the rotating Sen black holes. Also in this case, the gray/red shaded regions refer to the areas that are 1-σ consistent/inconsistent with the 2017 EHT observations).


Horizon
EHT allowed region
Shadow
Horizon
EHT allowed region
Shadow

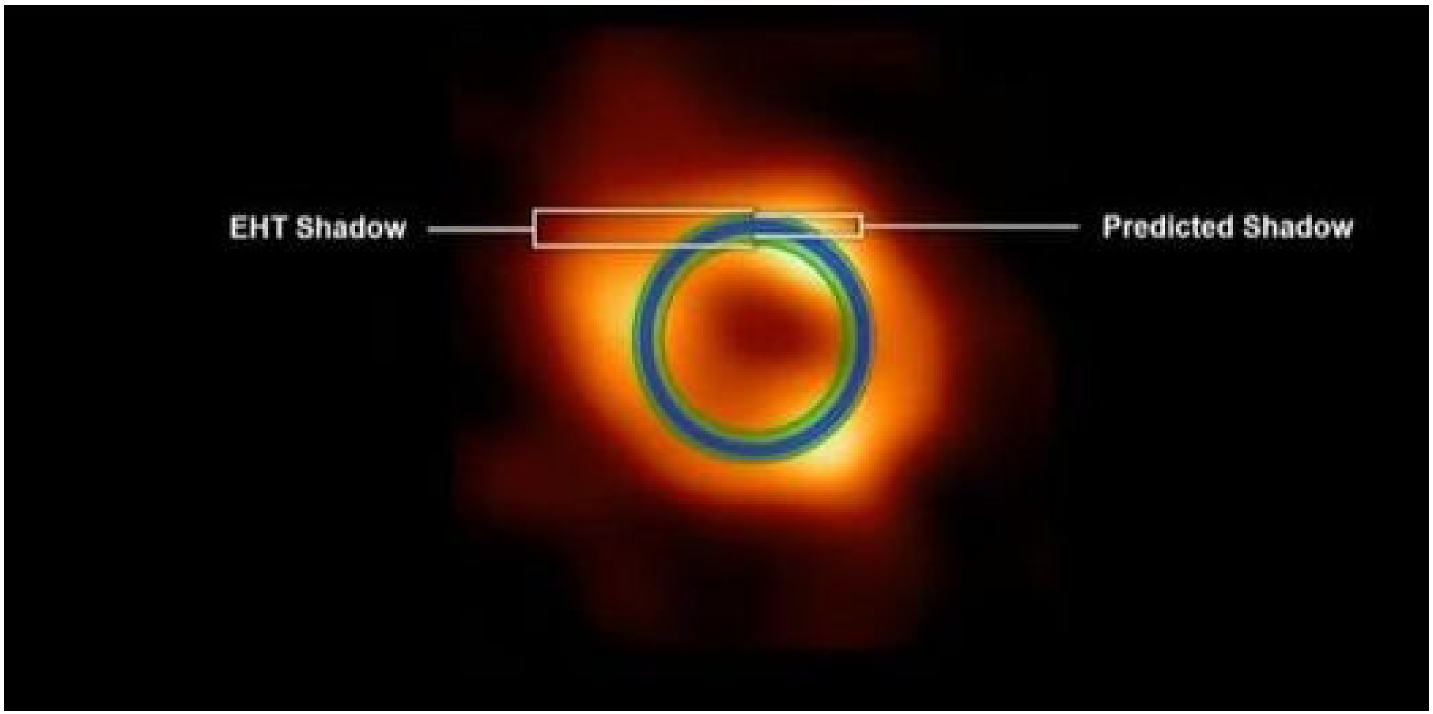
Sgr A* shadow discovery by EHT (reported on May 12, 2022)

Press Conferences around the world (Video Recordings):

Garching, Germany - European Southern Observatory

Madrid, Spain - Consejo Superior de Investigaciones Científicas
México D.F., Mexico - Consejo Nacional de Ciencia y Tecnología
Rome, Italy - Istituto Nazionale di Astrofisica
Santiago de Chile - ALMA Observatory
Washington D.C., USA - National Science Foundation
Tokyo, Japan - National Astronomical Observatory of Japan

For Sgr A* D=51.8±2.3 uas, (EHT collaboration, 12.05.2022)



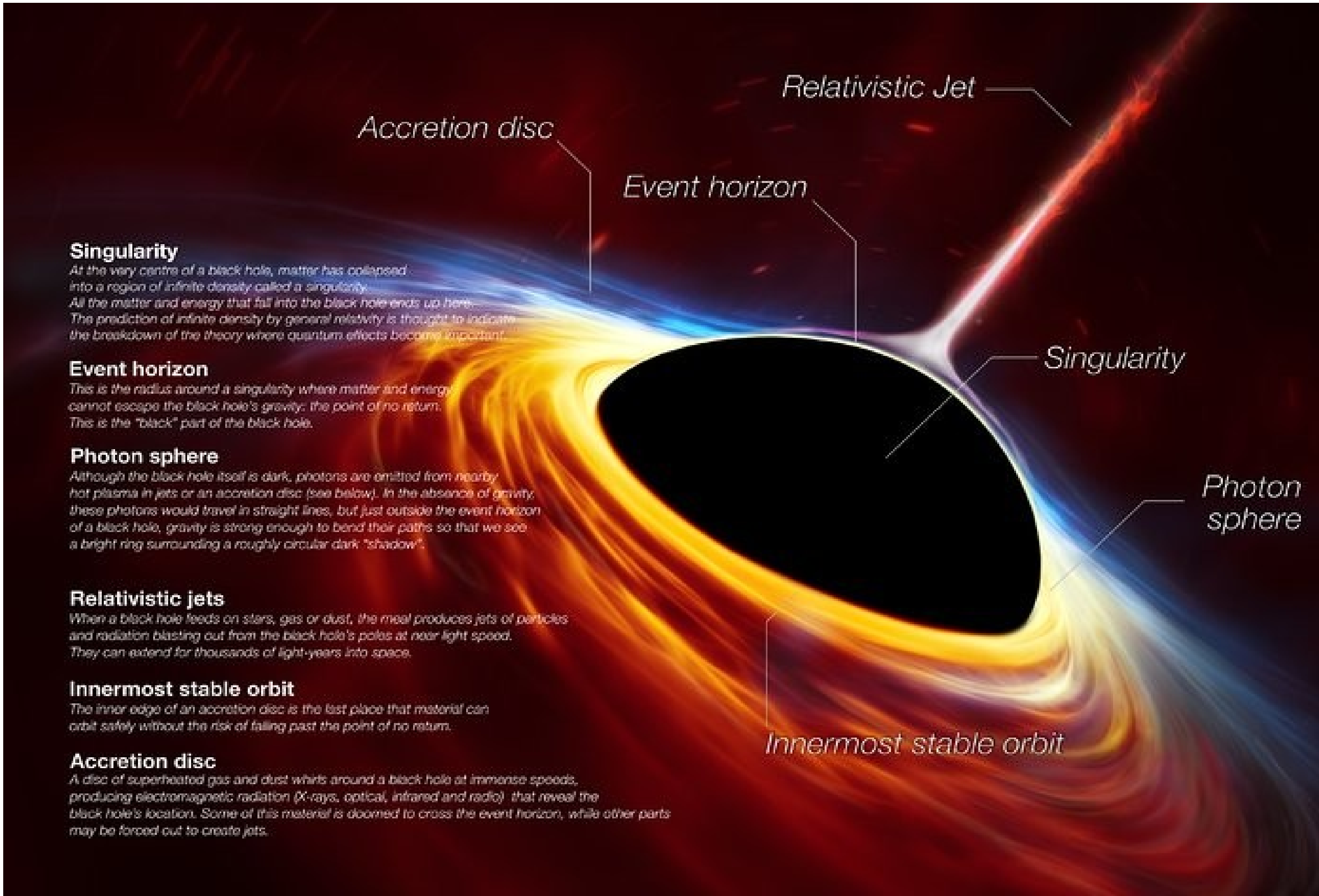
EXPLORING BLACK HOLES

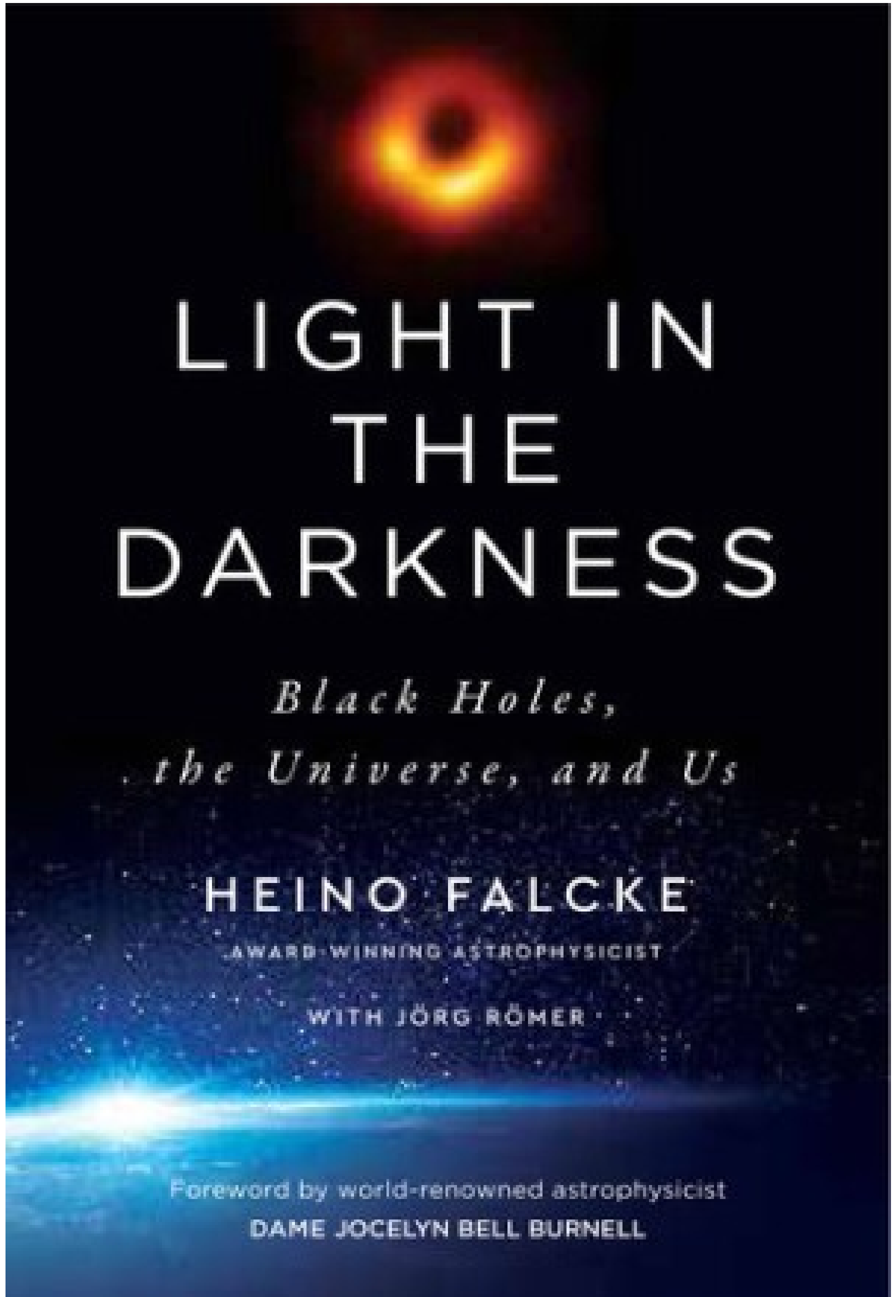
Introduction to General Relativity

EDWIN F. TAYLOR
JOHN ARCHIBALD WHEELER
EDMUND BERTSCHINGER

SECOND EDITION

The Event Horizon Telescope Picture




LIGHT IN THE DARKNESS
Black Holes, the Universe, and Us
HEINO FALCKE
AWARD-WINNING ASTROPHYSICIST
WITH JÖRG RÖMER
Foreword by world-renowned astrophysicist
DAME JOCELYN BELL BURNELL


ХАЙНО ФАЛЬКЕ
ПРИ УЧАСТИИ ЙОРГА РЕМЕРА
СВЕТ ВО ТЬМЕ
ЧЕРНЫЕ ДЫРЫ, ВСЕЛЕННАЯ И МЫ
КНИГИ ПОЛИТЕХА

Conclusion

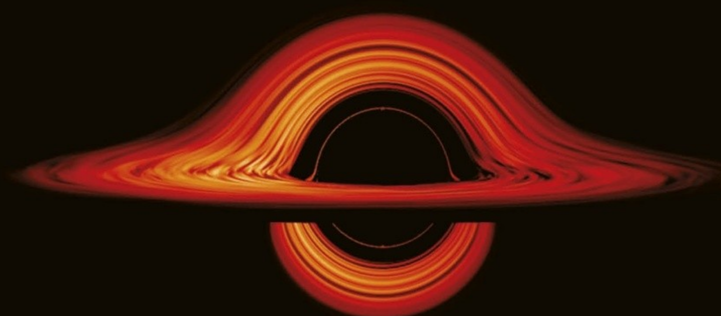
Very often our scientific community was not active in promotion of achievements of compatriots therefore, the achievements were underestimated or even not known in other countries.

The shadow concept has been transformed from a purely theoretical category into an observable quantity which may be reconstructed from astronomical observations.

Therefore, VLBI observations and image reconstructions for M87* and Sgr A* are in a remarkable agreement with an existence of supermassive black holes in centers of these galaxies.

‘A majestic story’
Financial Times

MICHIO KAKU



THE GOD EQUATION

The Quest for a Theory of Everything

V. S. Letokhov on colleagues

Even here in the USSR, no serious attention was paid to our work. The explanation is that others don't always understand that you are doing something really new. The scientific environment is quite conservative. They don't always like it when someone succeeds. Especially if this "someone" does not belong to one of the influential scientific groups.