BLACK HOLES:
THE CONCEPT BIRTH AND MODERN STATUS
(THEORY AND OBSERVATIONS)

A.F. Zakharov

Institute of Theoretical and Experimental Physics, Moscow, Russia

We discuss basic ideas which were foundations of the black hole concept. The major goal of the historical part is an attempt of an explanation of the very long way of the black hole concept birth, since the black hole solution was discovered by K. Schwarzschild in 1916, but the black hole concept was introduced by J.A. Wheeler only in 1967. We discuss the basic notions of the black hole theory and observational (astronomical) manifestations of black holes, for example, we analyse a possibility to interpret the very peculiar distortion of the iron K_α-line by such way.

Introduction

It seems that it is hardly possible to find other scientific concept, which as "black hole" concept would be so well-known for general people which are very far from theoretical physics and relativistic astrophysics. However, usually the (non-scientific) people know the concept essence very badly. As an example, one could remind some newspaper articles where there is information that using accelerator in CERN (Geneva) scientists created a black hole in a laboratory by artificial way and correspondents of newspapers asked scientists about a danger of the experiments for the world and scientists answered that their black hole have no possibility to capture the Earth, moreover the black hole does not present any danger for people which are very close from the accelerator.

1. Black hole concept appearance

1.1. Black hole concept in Newtonian theory of gravitation

Narlikar writes about with the first usage of the term "black hole" [1], moreover the term was used in historical chronicles but not in books on astronomy or physics. Namely, in summer 1857 the Bengal ruler Navab went to Calcutta to solve disputes with British East-Indian Company by force. British garrison was essentially less than Navab's army which has more than 50 thousand soldiers. However, during four-day battle Navab's army had huge losses and Navab commended to imprison 146 captives into black hole, into small prison cell which had sizes so small as 5 and 6 m. The cell had only two small windows. After 10-hour confinement from 8.00 p.m. on 20 June until 6.00 on 21 June (it was the hottest time of the year), 123 prisoners died. However Narlikar calls the reader's attention to a similarity between "Calcutta black hole" and its astronomical analogue, since one could speak about very strong concentration of a matter in the very small volume and there no exit from the volume.

The idea of a black hole began in 1783 with a British amateur astronomer the Reverend John Michell. He was a friend of Henry Cavendish and in a letter to Cavendish he discussed a calculation, based on Newtonian gravity, which showed that a sphere of the same density as the sun, but 500 times larger, would an escape velocity exceeding that speed of light [2]. Michell noted that such object could be detected as invisible companion in a binary astronomical system. One could note that Cavendish sent letter to Michell, where there was the first derivation of light bending in the gravitational field, so Cavendish founded the theoretical basics of the theory of the gravitational lensing, thus the correspondence of these scientists was very fruitful and the result was the very great contribution in a science development.

In 1788 P.-S. Laplace noted about similar result in his monograph “Description of the world system” and published similar calculation as appendix to the next edition of this monograph in 1799. One could find the English translation of this calculation as an appendix to the book by Hawking and Ellis [2].

1.2. Black hole concept in general relativity

In framework of general relativity which was discovered by A. Einstein in 1915, the German astronomer K. Schwarzschild in 1916 found the celebrated solution representing the geometry outside of a point mass. This solution describes the object which is called usually a black hole. So, the solution of the Einstein equation was found in 1916, but the black hole concept was introduced by J. Wheeler only in 1967. The main question is ”why did the concept have so hard development or was the half of century the time of a full calm in investigations in this field or was the black hole concept birth prepared contributions of scientists which are called rightfully like classics of science.

At first the metric was thought to be singular at the Schwarzschild radius

$$R_s = 2GM/c^2, \tag{1}$$

but the coordinate transformation found by Eddington showed that it is possible to move the singularity on the Schwarzschild radius [4]. However Eddington noted that R_s seems smaller than a radius of any astronomical object and hence plays no role in nature (we remind that $R_s = 1$ cm for Earth and $R_s = 3$ km for Sun.

But later it transpired the great role which could be played by such compact objects. At that Chandrasekhar’s article published in the beginning of thirties had a great significance. Chandrasekhar was very young when he prepared these articles. In July 1930, S. Chandrasekhar, who was only 19, was on a board a shipping from Madras to Southampton. He had been accepted by British physicist R.H. Fowler to study him at the University of Cambridge where Eddington was too. Chandrasekhar read Eddington’s book on the stars and Fowler’s book on quantum-statistical mechanics and as a result he was fascinated the problem of limit mass of white dwarfs. To spend the time during his trip Chandrasekhar asked himself: Is there any upper limit to how massive a white dwarf can be before it collapses under the force of its own gravitation? His answer made a real revolution in understanding physics of compact objects [5, 6]. Chandrasekhar concluded that above the critical mass the equation of state of relativistic degenerate Fermi gas of electrons is too soft to counter the gravitational forces; hence when considering the end evolution of such a star Chandrasekhar “left speculating on other possibility” [7].

But one of the most famous Soviet physicists L.D. Landau, in fact did speculate “following to a beautiful idea of Prof. Niels Bohr’s we able to believe that the stellar radiation is due simply to a violation of the law of energy, which law, as Bohr has first pointed out is no longer valid in relativistic quantum theory, when the **laws of ordinary quantum mechanics break down**” [8].

Eddington’s response to Chandrasekhar’s calculation was “when its (stellar) supply of subatomic energy is exhausted, the star must continue radiating energy and therefore contracting – presumably until at a diameter of a few kilometers, its gravitation becomes strong enough to prevent the escape of radiation. This result seems to me almost a *reductio ad absurdum* of the relativistic formula. It must at least rouse suspicion as to the soundness of its foundation. I do not think that any flaw can be found in the usual mathematical derivation of the formula. But its physical foundation does not inspire confidence, since it is a combination of relativistic mechanics and non-relativistic quantum theory. In the present paper this unholy alliance is examined. The conclusion is reached that "relativistic" (Chandrasekhar's) formula is erroneous" [9]. With the unfair advantage of hindsight we can now look back and see Landau and Eddington rejecting the implications of relativistic quantum mechanics rather then allowing the formation of a black hole [10].

In 1939 Oppenheimer and Volkoff discussed the possible existence of neutron stars and the end of stellar evolution and used general relativity (rather than Newtonian gravity) to examine the equilibrium configurations. Their conclusion was similar to Chandrasekhar's; stars consisting of cold neutrons, supported by the Fermi pressure and more massive than some critical mass "will continue to contract infinitely, never reaching equilibrium" [11].

In 1939 Oppenheimer and his student R. Snyder continued by examining the actual collapse of presureless star in the context of general relativity and concluded that no law of physics was likely intervene and stop at least some stars to form black holes [12]. As the authors wrote in their abstract "when all thermonuclear sources of energy are exhausted a sufficiently heavy star will collapse. Recently Novikov and Frolov noted that "every statement of this paper accords with ideas that remain valid today" [13].

However in 1939 Einstein had discussions about a possibility to create Schwarzschild singularities with Princeton cosmologist H. Robertson and his assistant P. Bergman. The problem lead Einstein to question about a possibility of such singularity existence in physical models. In his 1939 paper Einstein investigated the problem about a possibility "to create a field having (Schwarzschild's) singularity by gravitating masses" or tried to answer the question [14]: "Could such regions with vanishing component g_{44} be realized in real conditions?" "Thus, there is a question about possibility to introduce a matter in a theory to exclude all doubtful assumptions from the beginning. In fact it possible to do choosing the a great number of small gravitating bodies moving freely under an action of gravitational field which is generated by them. This system reminds the spherical cluster of stars. Therefore, we could act as we would consider the spherical symmetric field generated by continuous mass distribution corresponding to all particle aggregate. Below we could simplify our consideration assuming that particles move along circular orbit around the symmetry center of the cluster. But in this case we have a possibility to analyze the arbitrary radial distribution of mass density. The result of the following investigation is the conclusion that the component g_{44} can be equal zero nowhere and the total gravitational mass of particles which are inside a fixed radius is always less the defined value". As a result Einstein concluded that "**The main result of this investigation is clear understanding that "Schwarzschild singularities" do not exist in the real world** Although the analysed theory considered only such clusters where particles move along the circular trajectories, one could hardly doubt that the consideration of the general case would lead us to the same result". After publication of the so categorical statement about absence of Schwarzschild singularities in the real world hardly some scientist could have a temptation to investigate the object which does not exist in real world. As an example of the giant influence of the Einstein's paper one could cite the following statement from the classical textbook on general relativity [15]: "In reality, mass has no possibility to concentrate by the following way that the Schwarzschild singular surface would be in vacuum".

Preskill and Thorne wrote about very difficult birth of the black hole concept [16]. After our citation of the Einstein paper one could understand that even very remarkable and definite analysis of the gravitational collapse which was considered by Oppenheimer and Snyder [12] had a very small impact on the scientific society during many years. Oppenheimer and Snyder noted that if we consider the stellar collapse inside, the stationary observer sees the stellar surface moving to the Schwarzschild sphere and finally the surface freezes when the surface will be close to the Schwarzschild sphere. Moreover they clearly showed that observers which move with collapsing matter do not feel such freezing, such observers could cross the critical surface after finite self time and after that they have no possibility to send a signal which could be detected by distant observer who is located outside the collapsing matter. These two descriptions were not in accordance until 1958 when D. Finkelstein [17] analysed the Schwarzschild solution, using the coordinates which described simultaneously world line of photons which fall inside the critical surface and world lines of photons which freeze on the critical surface. The analysis discovered the unusual "causal structure" of the Schwarzschild space, namely any object will be involved inside a sphere with smaller radius. This result pointed out that after crossing the critical surface by the stellar surface, the stellar collapse which leads to the formation of the space-time singularity becomes inevitable. That is really the correct statement and that is independent on any assumptions idealizing the model, such as spherical symmetry and presureless, as it was demonstrated by R. Penrose [18].

Even J.A. Wheeler (who introduced finally the black hole concept) thought that results of Oppenheimer and Snyder are not true in general case. For example, Wheeler, Harrison and Wakano wrote that if we consider more realistic equation of state we will obtain qualitively different results [19]. This view would become less tenable as the causal structure of the black hole become properly understood. Gradually, however, Wheeler came to accept the inevitably of gravitational collapse to form black hole in agreement with the conclusions of Oppenheimer and Snyder. This shift of viewpoint was facilitated by insights of M.Kruskal [20], who had also clarified the causal structure of black hole independently from Finkelstein; in fact the essential part of this paper was written by Wheeler, though the insights and calculation were Kruskal's. But during the years (when Wheeler did not believe in results of Oppenheimer and Snyder), Wheeler reacted in characteristic way – he rarely mentioned Oppenheimer – Snyder results in his published papers.

This fact came to light when one of the most famous students of Wheeler and Nobel prize winner R. Feynman (who was under influence of Wheeler's insights on gravitation) noted in his lectures on gravitation [21] that it would be interesting to study the collapse of dust. He seems unaware that Oppenheimer and Snyder studied dust collapse **23 years earlier**! Moreover Feynman speculated that a star composed "real matter" cannot collapse inside critical circumference.

In the end of forties, both great scientists, Oppenheimer and Einstein, which proved and disproved the existence of black holes worked in the same Institute, namely in 1947 Oppenheimer became the director of the Institute for Advanced Study in Princeton, N.J., where Einstein was still professor. Chandrasekhar reminded that in the Institute in the end of forties the discussion was organized. The goal of the discussion was teaching general relativity in American universities. A general conclusion was there no sense to teach American students to give them basics of general relativity, because it is only mathematical toy, only three predictions are well-known etc. Chairman asked Einstein about his comments, but Einstein kept silence. Thus, it was accepted the solution about pointless to teach GR. In particular, one of the famous experts in GR, K.S. Thorne reminded that in the end of fifties (when he finished an education in Caltech) his professor said students "GR most probably is not necessary for astronomy except "Big Bang"". After that, Chandrasekhar was the first, who started in the end of fifties to teach GR.

Thus, there were the very strong rejection of the black hole concept, as a result of insights of Eddington and Einstein, which denied the existence such objects in nature (which are described by Schwarzschild solution and called now as black holes), the black hole concept was born only in 1967 and as a result of active efforts of such scientists as Chandrasekhar, Oppenheimer, Volkoff, Snyder, Kruskal, Finkelstein, Wheeler and others and people wait the event more than 50 years after publication of Schwarzschild's paper, since only on 27 December, 1967 Wheeler in his AAAS invited lecture annotated that "black holes predicted to result from "continued gravitational collapse" of over-compact mass".

Development of the black hole physics could be presented by the following periods [22]: prehistoric period, starting from the discussion of this idea by Michell (it was Michell who received the letter from Cavendish with the first derivation of the bending angle of a light ray in the gravitational field, and this essentially formed basics of the gravitational lens theory) and Laplace — who considered a possibility of an existence of such objects in the Newtonian theory of gravity in the end of XVIII century — and finishing in 1916 when Schwarzschild published his solution of the Einstein equations (the solution describes the static (non-rotational) black hole); the ancient history period, starting in 1916 and finishing on 29 December 1967, when famous American scientist J.A. Wheeler firstly introduced the term "black hole" in his lecture presented at the Hilton hotel in New-York (in the end of this period in 1963 Australian mathematician R.P. Kerr found the vacuum solution of the Einstein equations which describes the rotating black hole). From this Wheeler lecture a period of new history started — the "youth" of this new field of physics (according to the authors of the book, "heroic era of development of black hole physics"). This period is characterized by a rapid growth of investigations and finished in 1986 by the first edition of "Physics of black holes" by I.D. Novikov and V.P. Frolov (note that at the same time it were published an original English edition of the collective monograph by K. Thorne, R. Price, and D. MacDonald [23] — where a membrane paradigm in black hole physics is presented - which was translated into Russian in 1988 and also a Russian translation of a remarkable monograph by S. Chandrasekhar [24] published in English in 1983).

The modern era of black hole physics — from 1986 and up to present time — is the period of marvelous success in studying theoretical and mathematical aspects of the theory of black holes. But it is the discovery of compact objects in stellar binaries, which due to the words of the authors should be the black holes almost one hundred per cent, that becomes the main thing of this period. Besides, an intensive research of active galactic nuclei, being carried out in various spectral ranges, leads to necessity of existing supermassive black holes with masses of a few millions solar masses.

With hindsight to more than thirty-year history of the "black hole" term, we now see that it was this notion that just became a new paradigm contributing to an intensive development of relativistic astrophysics. Comparing this notion with the terms used earlier such as "frozen star" or "collapsar", we can see how the application of the last ones could limit the study of black holes. For instance, this would make a study of physical processes in horizon surroundings more difficult, more over it would be impossible to formulate statements on the processes inside the black hole horizon.

One can say — using mathematical analogy — that a use of the term "black hole" instead of "collapsar" is the same as using an actual infinity instead of a divergency sequence (or actual infinitesimal instead of sequence convergent to zero.) These mathematical notions (actual infinities and infinitesimals) earlier used by such classicists of science as Leibnitz and Euler, were introduced once again in mathematics a few dozen years ago on a necessary level of strictness and became a basis of so-called nonstandard mathematical analysis where a lot of theorem proofs, realized with actual infinities and infinitesimals and believed to be not strict enough, got a necessary mathematical strictness. Thus, such a notion as the actual infinity (or the actual infinitesimal) is the key paradigm in the nonstandard analysis and make it possible for fresh looking at the "standard" mathematical analysis. Just like this paradigm in the mathematical analysis such a notion as "black hole" is one of key notions in relativistic astrophysics.

It is obvious that a scientific notion must precisely describe a nature of an analyzing object, at the same time it should have some internal attractive power which would engage an interest of wide circles of society (along with black holes we could remind such notions as the relativity principle, dark matter, the inflation model etc). Really, in the late 1960s black holes transformed from the subject of studies of only experts on general relativity (in this time due to the words of the authors astronomers were very far from consideration of the black hole subject and even discussions on this did not welcome in a "respectable society") into the subject of everyday studies of astronomers and astrophysics (to make sure that one can have a look at volumes of "The Astrophysical Journal", Russian "Astronomy Reports" or the electronic library of preprints at LANL (Los Alamos National Laboratory)). The term "black hole" became enough ingrained in a social consciousness also, so, it is hardly probable to find another astronomical notion (all the more, the notion in general relativity) which would be so well-known even in wide circles being very far from astronomy and general relativity.

Apparently a black hole is the most perfect object in nature, since it is characterized only by three numbers: mass, angular momentum and charge. Wheeler expressed this statement as the hypothesis: "Black holes have no hair". Later, this statement was proved for stationary "Black holes, namely in the general case a stationary black hole is described by Kerr–Newman metric. Basing on the black hole studies it is considered that even in the case when a formed black hole was not stationary, it loses all characteristics from which a black hole could escape by radiation and thus the black hole becomes stationary. Therefore, a stationary black hole is a general case of black holes to a large extent, so the Wheeler statement is applicable to a large extent for all black holes.

2. Astrophysical black holes

Now a lot of astronomers believe now that black holes have been discovered yet. Usually the black holes are divided into several classes which depend on masses of black holes. The important classes are black holes of stellar masses and supermassive black holes. The detailed review on searches black holes of stellar masses was published recently by Cherepashchuk [25] and the comprehensive review on supermassive black holes is in the paper [26].

2.1. Black holes in stellar system

One could remind the limit mass of white dwarfs and neutron stars, namely, so-called Chandrasekhar's limit for maximal mass of white dwarfs is about $(1.2-1.4)\times M_{\odot}$, Oppenheimer – Volkoff limit for maximal mass of neutron stars is equal to $(2-3)\times M_{\odot}$. We note here that original estimates of these values which were obtained by the authors were in few times less and we presented here their modern estimates. Rotation could increase maximal mass of a non-rotating neutron up to 25% [13]. Do all stars with greater masses than $3\times M_{\odot}$ form finally black holes? No, of course, because there are a lot such processes like mass losses which are understood very badly. Thus, the initial mass of progenitors of black holes could be essentially greater than $3\times M_{\odot}$. Novikov and Frolov noted that according to recent simulations progenitor stars with masses about $40\times M_{\odot}$ could form black holes.

Probably the best evidence of the black hole existence comes from the investigations of binary X-sources, as it was predicted by Novikov and Zeldovich [28].

One could use the following arguments to prove that the system has a black hole [13]:

1. The X-ray emitting object is very compact, thus it could not be a neutron star or black hole. The argument comes from analysis of properties of emitted X-ray radiation.
2. Analysing data about the observed velocity of the optical companion star, one could estimate the mass of the compact star. If the mass of the compact object is greater than $M_0 \approx 3M_{\odot}$, it is a black hole.

One could note that this evidence is indirect, since we do not consider the specific relativistic effects, which are typical only for black holes. However, that is the best which could be considered by the modern astronomy [13].

According to common interpretation, now we have observational confirmation only for few binary X-ray systems. There are the serious reasons to believe that these compact X-ray companions are black holes. Some parameters of the most perspective candidates is presented in the table 1 (according to review by Cherepashchuk [25]).

The most reliable estimates of the compact object masses in these systems are essentially greater than $M_0 \approx 3M_{\odot}$. The most perspective candidates are such systems which have dynamical limit mass of the compact companion (so-called the mass function) greater than $3M_{\odot}$. We remind that the mass function $f(M)$ is determined as

$$f(M) = \frac{M^3 \sin^3 i}{(M + M_1)^2}, \tag{2}$$

where M is a compact component mass, M_1 is a mass of an optical companion star, i is an angle between the orbit and the direction toward to an observer. The mass function estimation procedure is described in the review in [25]. From this point of view the most perspective candidates are GS 2033+338 with $f(M) = 6.5M_{\odot}$, GS 2000+25 with $f(M) = 5M_{\odot}$ and XN Oph 1977 c $f(M) = 4M_{\odot}$.

Table 1: Black hole candidates in binary systems (from the review [25]).

System	Optical star spectrum	Orbital period (days)	Mass function (in units $M_{\odot}$)	Mass of compact companion (in units $M_{\odot}$)	Mass of optical companion (in units $M_{\odot}$)	X-ray luminosity (ergs/s)
Cyg X-1 (V 1357 Cyg)	O9.7Iab	5.6	0.23	7–18	20–30	$\sim 8 \times 10^{37}$
LMC X-3	B(3-6)II-III	1.7	2.3	7–11	3–6	$\sim 4 \times 10^{38}$
LMC X-1	O(7-9)III	4.2	0.14	4–10	18–25	$\sim 2 \times 10^{38}$
A0620-00 (V616 Mon)	K(5-7)V	0.3	3.1	5–17	~ 0.7	$\leq 10^{38}$
GS 2023+338 (V404 Cyg)	K0IV	6.5	6.3	10–15	0.5–1.0	$\leq 6 \times 10^{38}$
GRS 1121-68 (XN Mus 1991)	K(3-5)V	0.4	3.01	9–16	0.7–0.8	$\leq 10^{38}$
GS 2000+25 (QZ Vul)	K(3-7)V	0.3	5.0	5.3–8.2	~ 0.7	$\leq 10^{38}$
GRO J0422+32 (XN Per 1992= =V518 Per)	M(0-4)V	0.2	0.9	2.5–5.0	~ 0.4	$\leq 10^{38}$
GRO J1655-40 (XN Sco 1994)	F5IV	2.6	3.2	4–6	~ 2.3	$\leq 10^{38}$
XN Oph 1977	K3	0.7	4.0	5–7	0.8	$\leq 10^{38}$

The total number of systems mentioned as possible candidates of black holes with stellar masses is about 20 [13]. All these candidates are the X-ray sources in binary systems.

2.2. Evidences for black holes in galactic nuclei

Kormendy and Richstone divides the searches for supermassive black holes into three parts [26]:

1. Look for dynamical evidence of central dark masses. In practice, we look for high mass-to-light ratios. If M/L increases toward the center to values that are several times larger than normal, this is a meaningful clue because the range M/L values in old populations is small. Is there any escape from the conclusion that M/L is high? If not, then we have discovered a "massive dark object" (MDO). It could be a supermassive black hole, it could be a cluster of low-mass stars, or stellar remnants, or ot could be halo dark matter.
2. Once a few MDOs have been found, we need to improve the observations enough so that alternatives to a BH can be confirmed or ruled out. Proof of BH requires detection of relativistic velocities in orbits at a few Schwarzschild radii. This is not imminent. But in practice, the

plausible alternative to a BH is a cluster of stellar remnants; it would be already be important progress if we could rule out such a cluster on physical grounds. When we say that "we have evidence for a BH" in some galaxy, we mean we find such arguments persuasive. When we say "we have found an MDO" we emphasizing the uncertainty in arguments against BH alternatives. Step 2 of the BH search is just beginning.

3. Black hole astrophysics requires more than the detection of few examples. Ultimately, we want to know the mass function and frequency of incidence of BH's in various types galaxies. This requires the statistical surveys. Surveys are challenging because BH detectibility depends on galaxy type. Type-dependent biases will be a problem. In practice, we make statistical analysis in parallel with step 2. If MDO's turn out not to be BH's, the demographic results will nevertheless be important to our understanding of galaxy nuclei and AGN activity.

Some estimates of masses of black holes in galactic nuclei are presented in the table 2 (see paper [27]).

Table 2: Estimated masses of black holes in galactic nuclei. Data from Franseschini et al. [27]).

Galaxy	Black hole mass (in units $M_\odot$)
M31	3×10^7
M32	3×10^6
Milky Way	2.4×10^6
NGC 4594	10^9
NGC 3115	2×10^9
NGC 3377	1.4×10^8
M87	3×10^9
NGC 4258 (M106)	7×10^7
NGC 4261	9×10^8
NGC 4374	3.6×10^8
NGC 4486B	10^7

Novikov and Frolov [13] think that one of the most convincing evidences of the existence of black holes was given in an analysis of shape of some spectral lines, in particular iron emission line K_α.

Regular X-ray observations of Seyfert galaxies performed the last few years [30], have shown the presence of broad iron emission lines K_α (6.4 keV), as well as a number of weaker lines. The observed line widths correspond to velocities of tens of thousand km/s, which reach $v \approx 80000 - 100000$ km/s [30] for the galaxy MCG–6–30–15 and $v \approx 48000$ km/s [31] for the galaxy MCG–5–23–16. In many cases, the iron line has a characteristic two-peaked profile [30] with "high" blue maximum and low "red" maximum and extended "red" wing that gradually falls to the background level (see Fig. 1). Simulations which were discussed in the paper [29], demonstrated that actually observable line profile could be interpreted by emitting sharp ring which is located near a rotating black hole (a Kerr black hole) (see Fig. 2).

3. Are black holes inevitable?

Usually, when experts answer the question: "How high is a probability that black holes are at least in few known compact objects, in binary stellar systems or in some active galactic nuclei", they say "probability is *almost* 100%". What meaning has the word "almost"? First let us consider the stellar binary systems. If we believe that gravitational interaction is described by general relativity (now we have no convincing argument to rule out general relativity), then a compact object with a mass larger the critical mass must be only black hole. However, gravitational interaction could

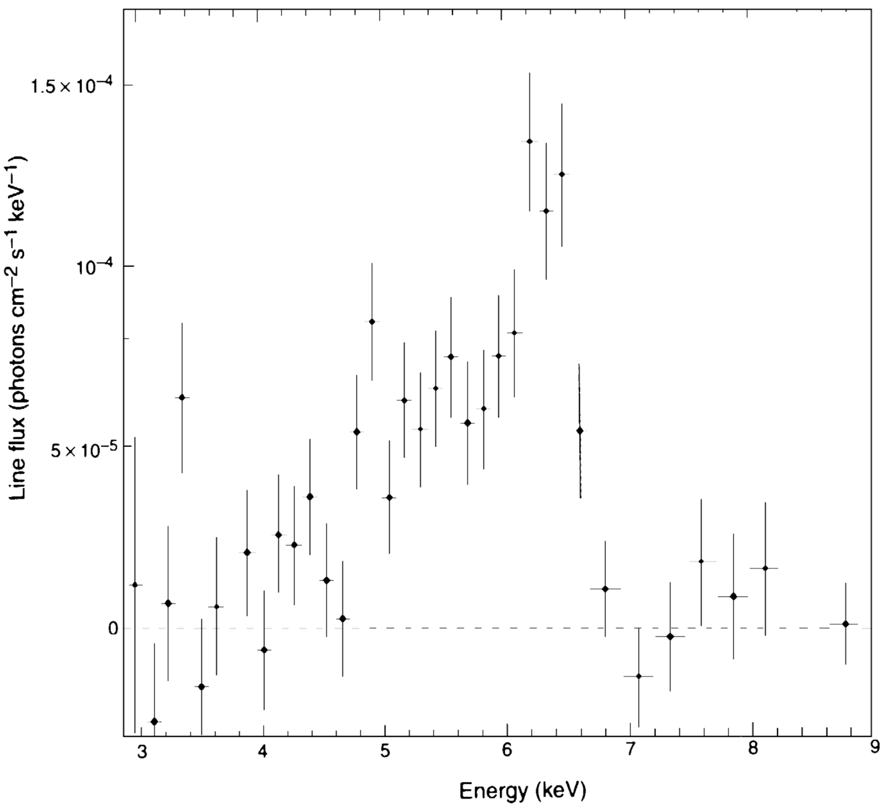

Figure 1: The line profile of iron K_α in the X-ray emission. The data have been rebinned to approximately the intrumental resolution. The emission line is very broad with full width at zero intensity about 100,000 km s^-1. (From the paper [30]).

be described by another theory. There is one of possible explanations of the usage of the word "almost" in the answer.

In the cases of supermassive black holes and nuclei of Seyfert galaxies the interpretations of the observable effects using black hole model look seem the most simple and natural, so following to Newton's call — "hypothesis non fingo" — we will not speculate and "discover" the models (or theories), when we have a possibility to explain observational data using well-known model (or theory). Moreover, during his history the black hole concept continuously finds additional confirmations and use for an explanation of observable astronomical effects which are related usually with the strong emission of energy, therefore, no doubt, that in future new astronomical objects, where black holes are, will be detected, as well as new physical phenomena will be discovered, which could be interpreted by clear and natural way using only the black hole model.

We would like to finish this articles by the words of the remarkable scientist S. Chandrasekhar, who investigated the black hole theory for several years in the end of his life [24]: "It is hardly probable that I would sin against the truth, confirming, that black holes are the most perfect objects in the Universe, since we need only space and time concepts for their determination, as general relativity predicts that the black holes are described by the only one family of solutions, one could think that they are also the most simple". According with the Chandrasekhar's statement now a lot of researchers see remarkable beauty and (and simplicity) of black holes.

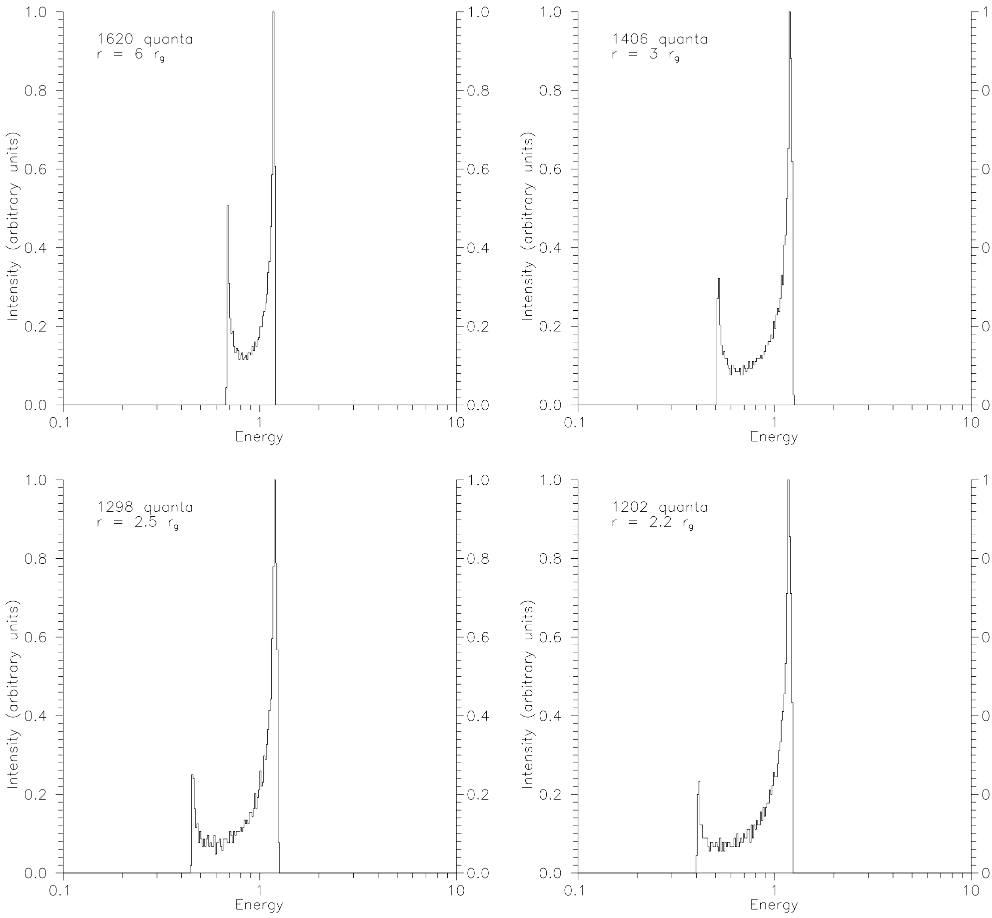

Figure 2: Distortion of a line shape as a function of the location of the emission ring for fixed values of the rotation parameter ($a = 0.5$) and the observer angle from the disk plane ($\alpha = 30°$). (Figure from the paper [29]).

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