On the Observed Mass Distribution of Compact Stellar Remnants in Close Binary Star Systems and Possible Explanations Proposed for the Time Being

Vladimir V. Sokolov

[1]*Special Astrophysical Observatory of Russian Academy of Sciences, Nizhnij Arkhyz, Russia;*

sokolov@sao.ru

Abstract It turns out that accumulation of data during 40-years observational studies just emphasized a contrast between pulsars and black hole (BH) candidates in Galactic close binary stellar systems: (1) the mass spectrum of these degenerate stellar objects (or collapsars) shows an evident absence of objects with masses within the interval from 2*M*ʘ (with a first peak at about 1.4*M*ʘ) to approximately 6*M*ʘ, (2) and in close binary stellar systems with a low-massive (about 0.6*M*ʘ) optical companion the most probable mass value (the peak in the mass distribution of BH candidates) turned out to be close to 6.7*M*ʘ. This puzzle of discrete mass spectra of collapsars in close binary systems demands some solution and explanation in stellar evolution scenarios in connection with the core-collapse supernovae explosion mechanism and in context of a relation between supernovae and gamma-ray bursts. The collapsar strong field – an analogue of BH in General Relativity – is investigated in a totally non-metric, dynamical model of gravitational interaction theory, in which extremely compact objects of the masses $M_Q \approx 6.7M_\odot$ with a quark-gluon plasma bag of radius $r^* = GM_Q/c^2 \approx 10$ km exist.

Keywords: Neutron Stars, Black Holes, Supernovae, Gamma-Ray Bursts, Dense Matter, Gravitation

1. Introduction

Compact stellar remnants in close binary systems (CBSs) have been studied systematically from the 80-th of the last century [1 – 15]. Now it is clear to everybody that there is indeed a considerable gap between masses of neutron stars (NS) and black hole (BH) candidates: the observed mass spectrum of NSs and BH candidates shows an obvious absence of compact objects with masses within the interval from 2 *M*ʘ to ≈ 6*M*ʘ.

Besides, the many-year investigations led to another observational property in compact objects themselves – the BH candidates in CBSs with relativistic companions. It turned out that, like NSs, they (BH candidates) can have a selected mass value. In 16 CBSs with low-massive (about 0.6*M*ʘ) optical companions the *most probable value* (a peak in a mass distribution of relativistic objects) is close to 6.7*M*ʘ. So, one can speak about a *discrete mass spectrum* of compact objects in the CBSs with NSs and BH candidates.

These two problems demand some solution both in the context of the supernovae and gamma-ray bursts (GRB) relation, and in connection with the core-collapse supernovae (CCSN) explosion mechanism itself. In particular, polarized radiation of long GRBs, the black-body component in their spectra and other observational properties can be explained also by a direct manifestation of a surface in such collapsars.

So, the main purposes in this overview are to draw attention:

(1) to the discussion about the discrete mass spectrum problem of the compact objects in the stellar CBSs,

(2) to 6.7$M\Theta$ peak in the observed collapsar mass distributions, and
(3) to probable interpretations the observed mass spectrum, which is rather similar to line one.

2. The Mass Spectrum of Stellar Compact Objects: Observational Properties

Though the mass distribution studies of compact remnants in binary systems have been carried out for a long time already (e.g., [1 – 12]), but astrophysicists keep discussing the mass spectrum problem of these degenerate objects for more than 20 years. Because,

On the one hand, according to General Relativity (GR), "a possibility to identify a compact object with black holes depends, in particular, on the condition that the available data allow positive asserting that the mass of an observed object is higher than the maximum permissible mass of a neutron star (or white dwarf)" (see [16], ch.9).

On the other hand, according to GR (see the same textbook by Shapiro and Teukolsky dedicated to The Physics of Compact Objects), the *mass* spectrum of compact objects (collapsars – NSs and BHs) in CBSs is likely to be continuum. (Since then nobody ever predicted that it must be discrete in GR at least.)

Though the observed mass spectrum is rather similar to the line one, see Figure 1 (a) taken from [7] and references therein. Evidently, there is a significant gap between the observed BH candidates and NSs masses.

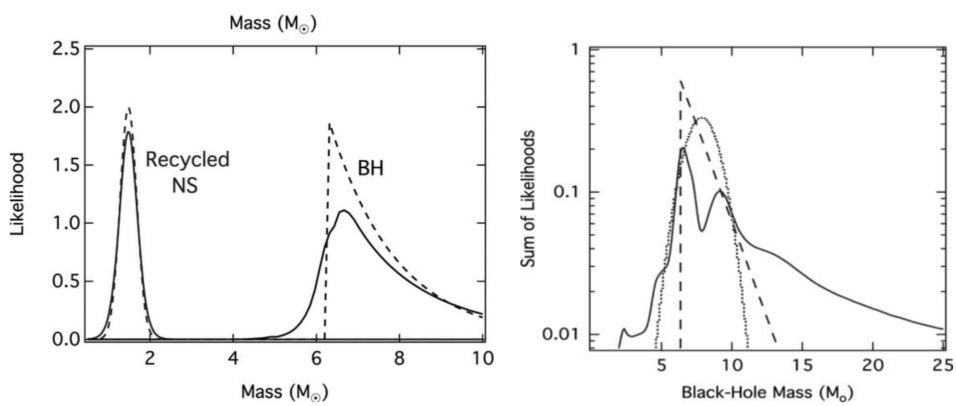

Fig1. *(Taken from Özel et al. (2012,2010)[7, 8]).*
(a) – The inferred mass distributions for the most massive neutron stars population (Recycled NSs) and BHs. The dashed lines correspond to the most likely values of the parameters. For the case of BHs, was used the exponential distribution with a low mass cut-off at Mc = 6.32MΘ and a scale of Mscale = 1.61MΘ. The solid lines represent the weighted mass distributions for each population, for which appropriate fitting formulae are given in [7]. The distributions for the case of BHs have been scaled up by a factor of three for clarity.
(b) – Solid line shows the sum of likelihoods for the mass measurements of the 16 BHs in low-mass X-ray binaries. The dashed and dotted lines show the exponential and Gaussian distributions, respectively, with parameters that best fit the data (see [8] for details).

Bailyn et al. (1998) [3] were among the first to find evidence of a "significant gap" between the least massive BHs and a "safe" upper limit for NS masses of 3$M\Theta$ (e.g., Kalogera & Baym (1996) [2], and see also [17] in page 3 where there are more references about this effect). Though the mass separation of the degenerate stellar objects was noticed as far as before 1990th for all CBSs including the Cygnus X-1 system (see references in [18] where one of possible interpretation of this gap is adduced for the time being). Here I say also, in particular, about of the compact object masses in 16 X-ray binary systems with faint (the low massive) optical companion stars. The tables of properties and orbital parameters for these 16 BH binaries can be found in Özel et al. (2010) [8] (and see also in Kreidberg et al. (2012) [11], Wiktorowicz et al. (2013) [19]). For these systems with BH candidates the companion mass ratio is $q = M_{opt} / M_x \approx 0.1$.

Just these very cases of the systems (with the mass of optical star M_{opt}) with uncertainties in measurements of binary system parameters are the smallest ones now, and the mass separation between the BH candidates and NSs is seen the most clearly. It is these systems in which the BH candidate masses are concentrated near maximum in Fig.1 (*a*). It is seen well also in Fig.1 (b) taken from [8] for the sum of likelihoods for the mass measurements of 16 BHs in low-mass X-ray binaries.

As was specially noted in [8], this cut-off mass $M_c = 6.32M\odot$ in the exponential distribution is well above theoretical expectations, indicating a sizable gap between NS and BH masses. Furthermore, the exponent mass scale $M_{scale} = 1.61M\odot$ in the exponents in Fig. 1(*a*) and Fig. 1(*b*) is significantly smaller than the same theoretical expectations. I.e. *the peak* of BH masses still turns out to be *rather narrow*. In this connection, the authors [7, 8] specially emphasize that because of the high-mass wings of the individual likelihoods, the shape of their sum in Fig. 1 (*a* and *b*) is artificial at the high-mass end. (About that see also the caption of Fig. 380, ch.8, §9, volume 2 of the book by A.M. Cherepaschuk (2013) [20]: "…the shape of probability density distribution function for all BHs in the region of high mass values M_x is unreliable".) This concerns also systems with a higher ratio $q = Mopt / M_x > 0.1$ and heavier optical companions (including Cyg X-1).

Figure 1 (*a* and *b*) actually is a good illustration of a new property – *the peak* in the BH candidate mass distribution. Figure 2 (*a*) is taken from paper [11]. Here the solid line conforms to what was obtained by other authors previously (by Farr et al., 2011) [10]: "Toward the end of our analysis work, we became aware of a more recent study [8], also in a Bayesian framework, analyzing the low-mass X-ray binary sample. Our results are largely consistent with those obtained by Özel et al. [8], who examined 16 low-mass X-ray binary systems containing BHs and found a *strongly peaked distribution* at 7.8 ± 1.0 *M*Θ."

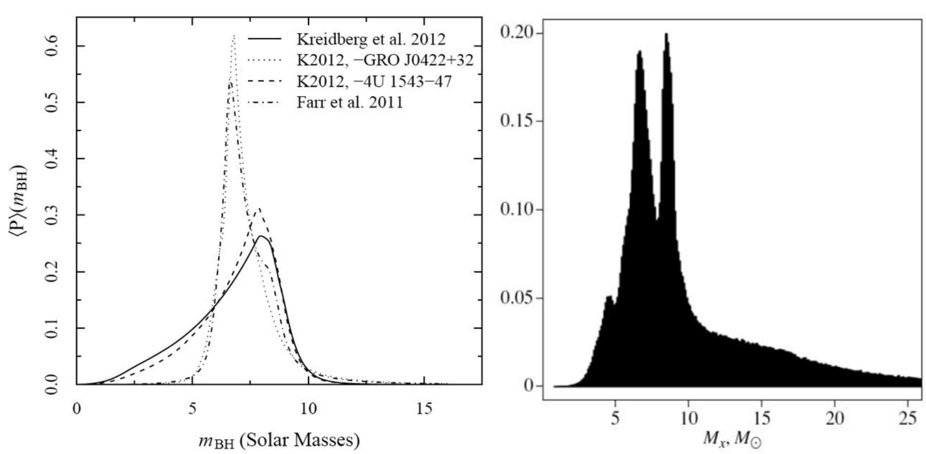

Fig2. *(a) – Different versions of BH mass probability distributions calculated in the power-law model taken from [11]. The dot-dashed curve is from the power-law analysis with the using of parameters of 16 BH systems of Farr et al. [10]; the dotted curve is from analysis with the using of parameters of 16 BH binary systems of Kreidberg et al. (K2012) from [11], excluding GRO J0422+32 from the sample; the dashed curve comes from analysis with system parameters from [11], excluding 4U 1543−47 from the sample; the solid curve is from analysis using parameters of 16 BH binary systems (but including GRS 1915+105 in the sample, see the text).*

(b) (taken from [13]) – Total probability density distribution of compact-object masses Mx in 20 X-ray binary systems (see the text).

For Farr et al. [10] this is the main conclusion which is well confirmed by this Fig. 2 (*a*) also. As was said above, from the paper by Özel et al. [8] it follows (see Fig. 1) that the parameterized probability density distribution for 16 BHs in low-massive binary X-ray systems obtained in the exponential law is optimal (the dashed line) with a *sharp break* in the low-mass end plus the fast downfall after this peak for large masses. This fast downfall of BHs mass does not agree with theoretical expectations (or predictions) also, as well as the sizable gap between NS and BH masses – see it in the article Özel et al. [8]. Here the matter is both about 16 CBSs whose parameters are measured the most accurately and about CBSs with heavier optical components for which "…the shape of their probability density distribution function for all BHs in the region of high values of mass M_x is unreliable" [8].

And here I am interested most of all in this peak itself (and its precise value especially) in the mass distribution of objects which many people already confidently call "black holes". Like the peak of NSs in Fig.1, the mass corresponding to *this peak* is a new observational property of real BH candidates in these CBSs.

Here astrophysicists can issue the challenge both on determination of the *minimum* mass (because there is this BH-NS gap) and on measurement of the limit mass for these objects (BH candidates), just as they do that for white dwarfs and NSs for a long time. All the more so, that now this already becomes the main observational and theoretical problem for NSs (see in Buballa et al., 2014 [21], and in this article below).

In Fig. 2 (*a*) from [11] the most probable value of BH candidate mass was perfectly confirmed after the strong testing of the same sample of objects and comparison of the BH mass distributions with previous results. But the main thing is this peak. And the filling of this NS-BH gap is "successful" only by taking into account the most unreliable binary system GRS 1915+105 (in which the corresponding individual probability/errors distribution in mass measurements of the compact object begins with the zero mass of the BH candidate – see Fig. 7 in [11]).

On the other hand, even with uncertainties of parameters measurements of the same 16 BH binaries introduced by GRS 1915+105 and another debatable system 4U 1543–47 (see the solid curve in Fig. 2, *a*), the result by Farr et al. [10] remains valid: *a strong peak* is in the sum of likelihoods distribution at 7.8±1.0 *M*ʘ (though with a lower maximum probability).

Recently, a SAI team [13] tested once more 20 binary X-ray systems with BH candidates by their methods and practically confirmed existence of the gap problem in the mass spectrum of the degenerate compact objects – NSs and BH candidates. The (*a*) and (*b*) images in Fig. 2 for BH mass distributions are similar, in spite of differences in the sets of binary systems, in their parameters, and in the methods (see [13] for details) of calculation of the sum probability used in these studies [11] and [13].

Thereby, calculations of probability distributions tested by four different groups ([Farr et. al. [10], Özel et al. [7, 8], Kreidberg et al. [11], and Petrov et al. [13]) by different methods confirm the main thing – a peak in mass distributions for BH candidates does exist really and (one way or another) it turned out to be within the Farr et al. [10] mass interval 7.8±1.0 *M*ʘ.

On the other hand, it is impossible to insert easily a BH in this gap in Fig.1 (*a*). In this mass distribution (see Fig.2 (*a*)) they try (see in [11] for the 1% mass quantile) to shift all 16 low-massive binary X-ray systems by only one system (4U 1543–47) just in the region where only NSs with mass not more than ≈ 2.1*M*ʘ [7] are observed. But, if we look at the individual probability/errors distributions (see in [11] Fig. 7), then we see at once the strong difference of the distribution for the 4U 1543-47 system from what was obtained by Farr et al. [10] for this system before (see Fig. 1 for the individual mass distributions in [10]).

Now, returning to the upper limit of this mass gap (2–5 *M*ʘ), as was said above, it can be even higher judging from what was obtained in [11]: the most probable value for the lowest BH mass is above 6*M*ʘ, with a peak at ≈ 6.7*M*ʘ for 16-1 X-ray binaries. This peak value was taken of directly from Fig. 2 (*a*). Here it is just the peak in the mass distribution that should be considered as the most probable value of the compact objects mass in these galactic CBSs. From this peak a downfall to the NSs side begins.

On the mass spectrum of BHs in the low-mass X-ray binaries: at least 16–1 of them holds the BH candidates with a mass distribution peak of ≈ 6.7*M*ʘ (as the most probable value – see Fig. 2, (*a*)). The authors themselves [11] wrote not a word about this peak. Though the result by Farr et al. [10] recalculated by Kreidberg et al. [11] in the scale ‹P›(m_{BH}) in the power-law model (marked by the dash-and-dot line in Fig. 2 (*a*)) also turns out to be close to the maximum near 6.7*MΘ*. That is, nobody except Farr et al. [10] wants to notice another observational fact beside this strange mass gap.

Everyone is keen on the problem to fill it (the gap) or, at least, to understand it. In doing so, nobody wants to explain or even to notice this peak itself (≈6.7*M*Θ) for the BH candidates. But analogous peaks (see in [7]) in NS mass distribution are explained somehow both by CBSs (+evolution) with NSs properties, and by the equation of state for these compact objects (neutron, hybrid and strange stars, see further about this).

As to peaks in mass distribution of BH candidates, here the ideological ban ("The BH mass distribution must be smooth, etc.") hinders from the very beginning. But eventually, just this observed BH mass distribution origin (with this peak from [8] namely right near 6.7*M*Θ) have to be explained from standpoint of *stellar evolution* of massive stars – see Figure 2 (right panel) in [40], and a discussion therein. But even here the authors do not indicate themselves in the text the mass value corresponding to the peak near 6.7*M*Θ in the BH mass function and one has to take it (the peak) directly from the image.

So, referring to the observed peaks in NSs mass distribution [7] one should pay attention to the fact that beside the strange NS and BH mass spectrum (with the characteristic lack of compact objects within mass range 2–5 MΘ) the matter can be about a new observational property of compact objects – BH candidates: Like NSs, these objects can have a selected (the most frequent in these CBSs) value of mass. Also this can mean perfectly that these observed objects can have a surface and their own equation of state the same as NSs… (No ideological bans can prevent us from testing that observationally. It is necessary to measure not only mass, but the size of BH candidates also.)

2. Gravidynamics

Here I call the gravidynamics some model of gravitational interaction ([22] and references therein) in which, like for all other fields in nature, the localizability of field energy is accepted a priori as a postulate. Then, with gravitational field energy densities close or exceeding the nuclear density $\rho_{\mathrm{nucl}} = 2.8\cdot10^{14}$ *g cm*-3, completely new properties of compact gravitating stellar mass objects can be prognosticated. In particular, the understanding of the physics of phase transition to quark-gluon plasma during formation of so dense objects can be directly connected with such dynamical gravitation description. Thus, the case in point can be the direct *observational consequences* related with the gravitational energy localizability.

The compact object (collapsar) strong field – an analogue of the BH in General Relativity (GR) – is investigated in such totally non-metric, dynamical model of gravitational interaction theory. In the case of extremely strong (for gravidynamics) collapsar field a region filled by matter ("a bag") must have a radius equal to $r^* = GM_Q/c^2 \lesssim 10$ *km* at the total collapsar mass $M_Q \lesssim 7M\Theta$. The article [22], dedicated to the properties of strong static field of the collapsar in gravidynamics, gives a more precise estimation of this mass and describes some properties of quark-gluon plasma inside this bag. Stability or hydrostatics of the *self-bound* quark-gluon bag based on the color forces only. Specifically, in the very centre (i.e., for distances $r \sim 1$ *fm* $= 1\cdot10^{-15}m$) of such a bag with radius $\lesssim 10$ *km* the "macroscopic" constant of the color forces will be only about 3 constants of electromagnetic interaction ($\alpha_{\mathrm{QED}} \approx 0.0073$). For all that the density $\varepsilon(r)/c^2$ will be of the order of 5.4×10^{52} $g\ cm^{-3}$, and the total energy (mass) in a so small sphere ($r = 1$ *fm*) will be $7 \times 10^{14}g \approx 10^{-19}\,M\Theta$. The total (*measurable*) mass of such *extremely compact* object is $M_Q \approx 6.7M\Theta$.

In another our article [23] dedicated to the masses of macroscopic configurations in metric and dynamic gravitation theories**,** a formula for calculation of the total mass of the extremely compact object in gravidynamics is given:

$$M_Q = 6.64 M_e \left(\frac{2\rho_{nucl}}{4B/c^2} \right)^{1/2}$$

for the bag radius $r^* = GM_Q/c^2 \approx 10$ *km* whose surface consists of a strange self-bound matter. This selected mass value 6.7*M*ʘ was obtained when we chose quite definite value of the bag constant B = 79.925 $MeV\ fm^{-3}$ for some quark-gluon plasma bag model in quantum chromo-dynamics (QCD) with limiting equation of state $P_Q = 1/3(\varepsilon - 4B)$ for quark configurations, where ε is the total energy density inside the huge quark-gluon bag with the bag radius $r^* = GM_Q/c^2 \lesssim 10$ *km*. And now it (the B value) is still discussed, but then it was possible to refer only to such pioneer papers as E. Witten [24] (see also the references in [23, 25]).

Thus, the gravidynamics is the model of gravitational interaction in which: (1) Gravitational field is assigned by energy and, correspondingly, quite a definite part of any gravitating object mass is the field energy like the electromagnetic mass of electron in electrodynamics. (2) All known relativistic effects of weak field (that is for $r >> r^* = GM_Q/c^2$) are explained (see [23] and references therein), because in such cases the force is basically specified only by a *tensor part* of field, or by gravitation proper. (3) In the compact object *strong field*, when the energy density of the field itself approaches the nuclear density ρ_{nucl} (for $r \approx r^*$), the role of the *scalar component* of the field (*repulsion*) increases. (4) The total mass M_Q of such an extremely dense object – a quark star in gravidynamics – already half consists of the field only, or of its *scalar-tensor* mixture around the bag with radius r^*. Thereby, the basic *observational consequence* confirming the version of gravidynamics + QCD unification suggested here, could be indeed the existence of a selected collapsar mass value M near 6.7*M*ʘ.

Relativistic effects in gravidynamics and in GR do coincide, but only in sufficiently weak fields (for $r >> r^*$), where GR describes them in the long run only as effects of the tensor field with the spin 2 graviton in flat space-time. This is the “Feynman approach” to description of gravitation (see Feynman Lectures on Gravitation [26]). But in strong fields, when the object size is close to GM/c^2 and when the energy density of the field itself becomes comparable with the energy density of matter (and of all other fields), the consistent dynamical description of field (gravidynamics) can give quite a different result.

In gravidynamics the observational properties and all physics of the quark star – a stable configuration with extremely strong field (for $r \sim r^* = GM_Q/c^2 \approx 10$ *km*) – are determined only and *uppermost* by the scalar component of the field or by “levitons” (from the word “levitation”) – “gravitons” with spin 0 [22, 23].

But then it already goes beyond the scope of the standard Feynman approach, in which “the theory with the graviton spin 0 must be rejected…” see the same Lecture 3 in [26]. So, the gravidynamics may be regarded as a certain modified or extended Feynman field approach to gravitation. In fact, in gravidynamics the most important and a critical question from the observational (experimental) point of view is the question: to which value of the gravitational field energy density in the strong field (this energy) cannot be considered non-localizable like in GR (see in [43], ch.11, § 96)?

In this article the matter is *essentially* about direct observational consequences of such consistent dynamical description of gravitation with two field components of spin 0 and 2. And here, in particular, I speak yet about a possibility to explain the second peak in the mass distribution of compact stellar objects (e.g., see Figure 1, left).

But here it should be specially said also about gravitational emission which explains secular effects in binary systems with pulsars. In gravidynamics we are to accurately account for contribution of scalar emission. Though in 1992 one attempt was already undertaken (see in [27]) for PSR 1913+16. But now modern data on binary pulsars became considerably more precise (see the references in the previous section). So far, there is a discrepancy from GR also for observed secular period changes *dP/dt* in these binaries. In particular, the observed *dP/dt* is higher and there is surely (see [28]) some unaccounted contribution, which should be taken into account carefully. It is especially important to take this into consideration in the case of relativistic collapse of a massive stellar core in the process of formation of objects with the mass 6.7*M*ʘ and radius ≈ 10 km. In this case the contribution of the leviton scalar radiation becomes determinative in gravidynamics.

4. Observations of Core-Collapse Supernovae, Gamma-Ray Bursts, Possible Explanations of the Observed Collapsars Mass Spectrum and stellar evolution

In connection with observational manifestations of these compact objects origin – collapsars (NSs and the BH candidates) – one should emphasize especially the discussion on a relation between BHs and long-duration gamma-ray bursts (GRBs), since NSs and BHs formation of itself can be closely related to GRBs. Here one should inevitably say about relation between core-collapse supernovae (CCSNe) and the same GRBs since a long-duration GRB can be the beginning of CCSNe. Or at least a GRB itself can be *one of first signals* of a massive star core collapse and supernova explosion at the end of the massive star evolution (see e. g. [29], and references therein).

The masses spectrum of compact remnants in binary systems is now actively discussed just in connection with the old problem of CCSNe explosion mechanism explanation (Wong et al, 2014) [17], because the CCSN explosion mechanism has remained one of the outstanding challenges in theoretical astrophysics for decades. Among the various models that have been proposed over the years to explain CCSNe explosions [30] (Müller & Janka, 2014), see also [31] (Janka, 2014) and [32] (Adam Burrows, 2012) for an up-to-date summary. The so-called *delayed neutrino-driven mechanism* currently remains the best explored and most promising scenario (at least for CCSNe with observed explosion energies not exceeding 10^{51} *ergs*). Still, see the remarks in [32]: "There has been palpable progress in the development of techniques and tools to address the core-collapse problem in the last thirty years, *but* the current status of the theory for the mechanism and the systematics of core-collapse explosions is ambiguous, if not confusing. Wilson (1985) [44], in a pioneering paper and using a spherical code, obtained a *neutrino-driven explosion* after a short post-bounce delay, …"

As was reported many times already [3, 8, 10], the problem of the "black hole mass gap" (or *paucity range*) of 2–5*M*ʘ demands some solution both in the context of the CCSN-GRB relation, and in connection with the CCSN explosion mechanism itself. The simplest "solution" is that the explosion energies are weaker for these stars, as it is understood by the authors in [32, 17] within the framework of their "fall-back mechanisms" in CCSNe. It is mean in hear, that some of the stellar material does not receive enough energy to escape the potential well of the newly formed NS and it falls back on to the core.

This is the fall-back which can be also connected to long-duration GRBs. At least, astrophysicists have been preoccupied with this strange "mass gap" for a long time, and *now directly* (at long last!) in connection with the SNe explosion mechanism itself, so long as one is forced to accept the fact that the details of CCSN mechanism are not fully understood**.** This means that it will be necessary to remember also the old *core bounce problem* in connection with SN 1987A [34]. The point is that *if a BH is formed* at once, then this "potential well" would become *infinitely deep*, and there would be *no CCSN explosion at all*. Therefore this catastrophic instability must develop before BH horizon emerges, what makes rather improbable the very accessibility of a BH configuration at the end of massive collapsing star evolution, and eventually QCD becomes incompatible with BHs [45] .

Wong et al. [17] suggest their version of a model of the core collapse massive star progenitors through the core bounce, in which the essential role is played by the neutrino transport. Philosophy of their calculations is that first they form above mentioned NS (to explain the CCSN itself), and then the further "fallback" leads to BH origin. This fallback (with a posterior BH formation) plays an important role in setting compact remnant masses and is to explain some observed phenomena likes of the long-duration GRBs and a neutrino emission. But unfortunately in such a scenario the resulting BH mass *must fill* the observed mass gap (or paucity range) 2–5 MΘ right now.

At least these calculations [32, 17] indicate that such a mass gap can indeed provide constraints on the physics of CCSN explosions.

But it turns out that problems (related to the compact objects characteristic mass lack 2–5 MΘ) arise already in origin explanation or *evolution* of the same CBSs with the low-mass optical companions and with $q = Mopt/M_x \approx 0.1$. Right in connection with the formation puzzle, the authors of [19] (Wiktorowicz, G., Belczynski1, K., Maccarone, T.J. 2013) try to explain just this (observed) value *q* in the 19 reliably confirmed now BH Galaxy binaries or in the BH X-ray transients. The 16 of them are X-ray transients (or the BH low-mass X-ray binaries) hosting ~ 5–10 *M*Θ BH candidates and a Roche lobe overflowing low mass optical companion. The observed *optical companion* masses are found mostly in 0.1-1 *M*Θ mass range, but with a *peak* at 0.6 MΘ. Under such conditions none of the available common envelope models allow for the formation of the *observed* population of Galactic BH transients with masses from Figures 1 and 2 though.

That is, one cannot explain just these too small masses for the optical companions (M_{opt} = 0.6*M*Θ). According to all known standard (and described in many textbooks in detail) evolution models of such CBSs, it must be 1MΘ**.** That is to say, the optical companion mass distribution must peak at 1MΘ also. But at least it is still in tension with the smallest measurement errors in mass measurements for these 16 binary X-ray systems.

So, the sum of all explanations of component mass ratio $q = Mopt/M_x$ in these 19 BH X-ray transients is as follows.

Wiktorowicz et al. [19] have reexamined the issue of donor (optical star) mass in the Galactic BH X-ray transient binaries. Since the formation scenarios involve a common envelope phase initiated by a massive BH progenitor, it is naturally expected that companion mass should not be too small as to avoid the common envelope merger. However, the donors that are found in the BH X-ray transient binaries have very low mass ≈ 0.6*M*Θ. Early studies have shown that stars with mass above 2 *M*Θ are the most likely companions for Galactic BHs (CygX-1 e.g.). With the updated population synthesis code by Wiktorowicz et al. [19], they have shown that stars with mass 1 *M*Θ are most likely companions. Despite the factor of ~2 improvement the predictions are still *in tension* with available (the most exact) observations.

“This failure most likely indicates that either the current evolutionary models for low mass stars are not realistic or that the intrinsic population of BHs per se (in the low-mass X-ray binaries) is quite different from the observed one” (see the remarks in [19]).

Though for the time being Wiktorowicz et al. [19] do not pay attention to the peak itself in mass distribution of the BH candidates, but they are very concerned about this “mass gap”: In the NS and BH mass spectrum the characteristic lack of compact objects is within mass range 2–5*M*Θ – this is close to the interval between the maximum mass of NS and minimum mass of BHs (candidates). In this connection, when speaking about the interval between the “last” peaks (Fig.1, solid lines), i.e. between the most probable values of mass of compact objects in galactic CBSs, it would be close to 1.4–6.7 *M*Θ. I.e., the gap begins indeed with *a fast downfall* of mass of compact objects both from the NSs side (1.4 *M*Θ peak) to BH candidates, and from the BH side (6.7 *M*Θ peak) to NSs side.

Eventually *another* model of supernovae was suggested for the gap in the mass spectrum of compact objects [19] – this gap can be *qualitatively* explained with the specific model of CCSN explosion. But in the same model [35] (Belczynski, K., Wiktorowicz, G. et al. 2012) have to take into account the fact that the *lowest mass* BHs are above 5*M*Θ in correspondence with the fact that the maximal mass NSs are less than 2*M*Θ. “So far we have not directly commented on the associated BH mass distribution of the BH X-ray transient binaries. In all previously discussed models BH masses were found in 5–15*M*Θ range. This range is in agreement with the existence of mass gap and consistent with masses of BHs in the Galactic binaries” (see the remarks in [35]). At least, here the authors admit themselves the existence of a problem.

Though eventually just in this new model of CCSN explosion by Belczynski et al. [35] it also turns out that BHs (resulting from the explosions) get directly to this gap: “In this model we find that majority of BHs have mass around 3*M*Θ.” So, and this finding is inconsistent with the observations, since “it is hard to imagine that currently known wide spectrum of BH masses would be shifted to a very narrow range with peak at ≈3*M*Θ.” And then, peak like this for the BH candidates turns out to be at a wrong place (see in Fig.1).

Besides, it should be also taken into account that the limit mass of observed NSs is not 3,2*M*Θ, but is ≈ 2*M*Θ. I.e. there are no NSs with such limit masses (≈ 3,2*M*Θ) and limit equation of state P = ε, which was mentioned in the famous textbook by Shapiro and Teukolsky (see chapters 8.13 and 9.5 in [16]). So, the prediction based on the wrong theory of strong interaction failed here also – NSs and BHs with mass 3.2 *M*Θ are not observed.

4. Conclusion

As far as before 1990 it was said that a strange minimum between masses of NSs and BH candidates is outlined, but then nobody took it seriously. Accumulation of data on CBSs with the degenerate objects has been going on.

When I. M. Kopylov with me [14] were determining the mass of the first (at that time) CBS Cygnus X-1 with the relativistic companion, we concentrated then on the most precise estimation of mass of the optical star HDE 226868 – OI supergiant. It was what should be done first of all and as precisely as possible, because then it would be possible to determine reliably the *lower bound* of the degenerated star mass also. It turned out that with the mass $M_{\rm opt}$ = 19.5*M*Θ, the mass of the BH candidate must be *not less than* 6.5*M*Θ.

It is this value of the mass $M_{\rm opt}$ in CygX-1 system that is cited in [19]. Eventually it turned out that this lower mass limit $M_x \geq 6.5M\Theta$ [15] of the relativistic object in CBS Cygnus X-1 is close to the low mass cut-off at $M_c = 6.32M\Theta$ in the exponential mass distribution as shown in Fig. 1 (a).

Now the data precision on BH candidates in the Galactic binary systems approaches to the precision of NS mass data, and they can be compared at last; there are a lot of papers about that already (see refs. at the Section 2). Certainly, they are superimposed by *individual* errors of mass determination in such binary systems and by a *real mass dispersion* of the compact objects themselves resulting from star evolution in these CBSs (see at the Section 4 of the text). But, one way or another, the peaks in mass distribution in Fig. 1 and 2 (*by definition*) are the *most probable mass values* of these degenerate objects.

So, it turns out that the accumulation of data on Galactic CBSs with degenerate stellar objects during 40 years just emphasized the *contrast* between NSs and the BH candidates. There are no compact objects with masses between 2*M*Θ and ≈ 6*M*Θ, and what is more, – there is the peak in their mass spectrum near 6.7*M*Θ (see Figs 1, 2). Thus, the previous sections concern the value of mass of a quark star (extremely compact object) in gravidynamics $M_Q \approx 6.7M\Theta$ [23] predicted in 1993. Besides, now it can be considered also as an independent observational confirmation of the quark-gluon plasma bag model in QCD, because the value of the bag constant $B = 79.925$ $MeV\,fm^{-3}$ in the limiting equation of state $P_{\rm Q} = 1/3(\varepsilon - 4B)$ follows immediately from the value of the second peak ≈ 6.7*M*Θ as the most probable value in the observed distribution of mass of degenerated objects of stellar mass in CBSs, i.e. where these masses are measured the most precisely at present.

It is not excluded that further observations will result in the fact that these compact objects (in these binary systems) can be without BH properties like singularity or event horizon. Like NSs, these degenerate objects can have their own equation of state, surface and size, determining all their observational manifestations. The absence of the pulsar effect in objects of the second peak in the mass distribution in Fig.1 does not mean that they do not have surface. This only means that these are not pulsars or NSs**,** at least. Therefore it is still early to say that these are BHs exactly, and BHs are discovered already. We *can* and *should* look for effects related to the surface of these objects because many people realize that GR predictions still remain to be verified in the strong-field regime (see e. g. [41, 42, 46] and references therein).

In particular the GRBs prompt emission anisotropy, the instantaneous GRB blackbody spectra and other observed properties (e. g., well-known “Amati law”) must be a consequence some sort of compact GRB model [36] and could be explained by the direct surface manifestation of these collapsars. And strong linear polarization of some GRBs prompt emission can be also explained in principle by the direct manifestation of strong magnetic field of a collapsar resulting from an SN explosion, and may be related to radiation transfer in a medium with the strong (regular up to ~10^{12} - 10^{16} Gauss) magnetic field on (or near) the surface of the compact object [39]. And a cyclotron feature E_{rest} = 21.7 (+1.9/-1.6) keV (for GRB 011211 with gravitational red-shift z_{grav} = 0.318) could be explained by the *direct* manifestation of the surface magnetic field of ~10^{12} Gauss in the GRB photon gamma-ray spectrum [33] with z_{GRB} = 2.140.

On the other hand, the problem of a too large mass of NSs is also actively discussed now. The main point is, – what these objects consist of? See the recent discussions in [21] and NEOS2014 (The second workshop on "Nuclear Equation of State for Compact Stars and Supernovae", FIAS, Frankfurt, December3 – 5, 2014, http://fias.uni-frankfurt.de/~neos2014/). And what maximum permissible mass can be reliably justified for NSs; 1.4*M*ʘ or 2.2*M*ʘ? Now the equation of state is the main problem for these objects (of the first peak in the mass distribution in Fig. 1) also. Are they neutron stars? (See also [37] and references therein.) Thus, already physicists are also excited by the mass distribution (with the peak 1.48*M*ʘ in Fig. 1). The NSs masses near 2*M*ʘ are permissible in this distribution. But such objects are too heavy to be called NSs – see also the review by J. Lattimer [38] “The Nuclear Equation of State and Neutron Star Masses”.

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