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ON PROPERTIES OF STRONG GRAVITATIONAL FIELD OF A COLLAPSAR IN GRAVIDYNAMICS

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ABSTRACT. *A contemporary state of investigations of compact objects with utmost strong gravitational field - collapsars with masses of the order of solar - is considered in brief. If theoretical model of such an object is a black hole of general relativity (GR), then a crucial experiment must be reduced to the exclusion of surface signs analogous to signs of a solid surface for neutron stars. Since the surface signs are excluded for no collapsar under investigation, the properties of alternative collapsar model in the bounds of dynamics (totally nonmetrical) theory of gravitational interaction are considered. In gravidynamics (GD) the mass of any object must include also the mass of its "coat" of virtual gravitons, which always stretches beyond "the event horizon" of GR. In gravidynamics the collapsar always has a surface. It is the surface of "a bag" - a region filled with matter. The bag radius is equal to* $r_*=GM/c^2$ *when the total energy of the whole configuration "bag+field" is* Mc^2.

I. INTRODUCTION

Extreme conditions corresponding to high barion densities in experiments on collisions of heavy nuclei correspond to titanic *macroscopic* densities existing in the entrails of neutron stars and (hypothetic) quark stars. For such objects (with masses of the order of several solar masses) the gravitation becomes an interaction not only essential but determining their basic properties. The paper continues the investigation of collapsars, i.e. objects with *strong* and may be the utmost strong gravitational fields (existing really in space only).

Specifically, such objects can be in particular galactic X-ray sources which are massive (with masses $\geqslant M_\odot$) *compact* objects accreting the gas in close binary systems (CBS) of stars with a characteristic accretion rate $\dot{M}\sim 10^{-9}\ M_\odot/\text{year}\approx 6.4\cdot 10^{16}$ g/year (Shapiro, Teukolsky, 1983). High X-ray luminosity ($L_x\approx 10^{37}-10^{38}$erg/s) at such $\dot{M}$ is connected here with the energy discharge in a rather *small* region comparable with the gravitational radius (GM_x/c^2). The luminosity L_x can be estimated (*roughly*) by the formula:

$$L_x\sim\frac{GM_x/c^2}{R_x}\cdot\dot{M}c^2,$$

where R_x is a characteristic (minimal?) radius of radiating region. When the mass $M_x\approx 1.4M_\odot$ and $L_x\sim 10^{37}$erg/s, $R_x\geqslant 10$km and $GM_x/c^2/R_x\geqslant 0.2$. The rapid variability of X-flux at times $>R_x/c$ is a very essential additional testimony of compact character of such objects.

From the point of view of physics, the case corresponding to the *strong* gravitational field of a compact object coincides with the situation when (on the one hand) *macroscopic* mean densities of such objects are *not less* than nuclear ones and achieve supernuclear densities, and (on the other hand) corresponding *macroscopic* energy densities of *gravitational field* on the surface of such objects can become equal or even larger than $\rho_{nucl}\cdot c^2$. In such a *dynamic* approach to the field energy problem the study of macroobjects with strong gravitation is analogous to experiments on accelerators in which it is necessary ultimately to approach the center of electron or quark, penetrating deeper into their "fur coat", using such notions as running coupling constant, asymptotic freedom, confinement, the mass of block and current quarks...

Thus, below we will discuss the objects with masses of the order and larger than $M_\odot$, for which the region filled with matter is of the order of their gravitational radius $r_*=GM_x/c^2\approx 10$km. Such object (not hypothetic one for a long time) as a *neutron star* (NS) with the mass $M_{NS}\approx 1.4M_\odot$ and the radius about 10km can be an example of the object with a strong gravitational field. As a rule, NS (in CBS) is a bright ($\approx 10^{37}$erg/s) X-source. But the basic property which allows us to identify a lot of such X-sources with NS namely is the presence of the effect of *pulsating* radio, optical, X- and even γ-radiation. In all the theoretical models the phenomenon of pulsar in NS is connected with the existence of their solid *surface* with definite physical properties.

The second feature which allows us to identify some X-sources with NS is their mass. In the cases when X-source - the pulsar - is in CBS, its mass can be determined rather precisely. The value of the mass of a typical NS which was adduced above ($M_{NS}=1.4M_\odot$) follows, in particular, from the result of data analysis of an experiment of many years with the radiopulsar PSR1913+16 in a CBS. In this natural laboratory with a rapidly variable ($P_{opt}=7.75$ hours) gravitational field the masses of both the NS consituting CBS are measured with (almost!) celestial mechanical precision

($M_1=(1.386\pm0.003)M_\odot$, $M_2=(1.442\pm0.003)M_\odot$) (Taylor, Weisberg, 1988).

The basic question for the theories of gravitation has always been and remains the following one: What can, however, occur when we deal with objects which *are not less compact* than NS but which are *more massive*? Or what is the fate of a *compact* object with a mass larger than $3M_\odot$?

Astrophysical experiment says that such objects are really observed. That is why the question once posed by physicists looks now as a concrete *astrophysical problem.* What are the objects or *what is the physics* of X-sources in such CBS as CygX-1, A0620-00, LMCX-3 and LMCX-1 (Cherepashchuk, 1989)? All the objects have masses close to a value of about $6M_\odot$, all of them are compact X-sources, all of them do not show the pulsar effect which is characteristic of NS.

The solution of the question (the problem now) was first suggested in the bounds of GR, where the *limit* value of the mass of a cold NS ($<3M_\odot$) was calculated. But to be precise, it is not clear up to now whether the solution is correct or not. From Eddington's time doubts remained whether *the event horizon* exists really in Nature, which is a basic property of "black holes" that are *a theoretic model* of a compact *"supermassive"* (with $M>3M_\odot$) object in GR.

Indeed, from the point of view of GR compact X-sources with masses *greater than* $3M_\odot$ must have *the event horizon* but not the surface (as NS, for example). The question about the fate of such "supermassive" objects is reduced now to *experimental* (observational) elucidation of the question of principle in GR whether such candidates as CygX-1, A0620-00, LMC X-3 and LMC X-1 have the event horizon but not *the surface.* Here the surface of a compact object means matter in an equilibrium bound stationary state (and, of course, with a finite red shift).

It is in *this* concrete posing of the old problem that there is no reliable experimental answer to the question up to now, i.e. one can not assert confidently that a compact object with a mass of about $6M_\odot$, for example in the system CygX-1, has the *physics* indicative of physics following the theory of black holes (Novikov, Frolov, 1986).

Since the black hole remains yet a hypothetic object with a high probability, a *crucial experiment* "horizon-surface" remains urgent up to now. Such an experiment is connected with penetration deeper and deeper into a massive gravitational "coat" surrounding a compact gravitational object, provided one adhere to a *dynamic* treatment of gravitational interaction, which is correct in the case of all other gauge fields. Such experiments in a strong gravitational field are connected with the analysis of radiation arising as a result of events (processes) in regions with a limit *density* of matter ($>\rho_{nucl}$ and larger) and *gravitational field.* Ultimately it is the analysis of *hard* and *extremely fast changing* component of X-radiation, γ-radiation...

2. WHY "COLLAPSARS"?

All the compact objects (radiopulsars, gamma-ray bursters, X-ray bursters) and, in particular, bright binary X-sources can be divided into *two big sets*. The same (not rather standard) division is made here for *the separation* of NS from objects with more incomprehensible (or with absolutely incomprehensible) *physics*.

First set. It contains X-sources which are interpreted, as a rule, as NS. The basic argument is certainly a pulsating X-radiation (optical, radio and γ-radiation) with a stable period. In particular, the interpretation of X-pulsar demands a solid *surface* of a compact and rotating object and *an inhomogeneity* on this surface which can be created by a strong ($>10^{12}$-10^{13}G) and *asymmetric* magnetic field (an "oblique rotator"). In such a case the plasma accreting on the surface "is channelized" by a magnetic field, which results in the fact that the impact of the falling matter which produces short flares - "pulses", occurs not on the whole surface but only in the region of the "spot".

If such an X-pulsar is really in a close binary system (and this is a frequent case for bright ($L_X \approx 10^{37}$egr/s) X-pulsars (Aslanov et al., 1989), then its mass can be determined rather precisely. And if it is close to a *"canonical"* value 1.4 $M_\odot$, then the conclusion is almost inevitable that we deal with NS and not with anything else... But such a good combination of astrophysical conditions ("binary pulsar") is not a common case. Often one can estimate the mass of X-source in CBS (close binary system) to be close to 1.4 $M_\odot$ and in any case less than 3 $M_\odot$, but there is no pulsar effect. In such a case it is necessary to assume either sufficiently weak magnetic field ($<10^9$ G) or an "oblique rotator" orientation "bad" for a ground-based observer. Certainly a coaxial rotator is not excluded. In such cases the determination of physical characteristics of CBS is often indirect, when one has to use different models for gas accretion flow on the compact object or different models for thermo-nuclear burning of matter near the surface of NS...

In any case there are already rather many objects which can be most probably NS: 36 compact objects - pulsars contained in CBS only (Aslanov et al., 1989). In these cases one can assert with some confidence that the mass value of a compact companion of CBS is close to 1.4 $M_\odot$ and *does not exceed* 3 $M_\odot$. Of course, several hundred (>400) radiopulsars should also be included into the first set of compact objects.

Second set. But the more model considerations are taken into account when determining the mass of compact objects - nonpulsars (X-ray bursters and *especially* γ-ray bursters) the lower confidence is natural to these estimations. Strictly speaking such compact objects should be included into the second set of objects-*nonpulsars*. And "ordinary" neutron stars NS can be surely found among them. Though now the situation became more intricate because a new type of *stable* compact objects is discussed confidently (Haensel, 1987; Krivoruchenko, 1987) with macroscopic densities more than ρ_{nucl} and masses the same as those of NS. These are the so-called "strange stars" or quark stars (QS) whose physics can be different from that of NS (surfac which results in corresponding (vague so far) observational consequences between and QS. Here, in the second set of compact objects which contains, in particular, sources, the objects are included which can be hardly identified with NS. Those (n *numerous*) cases when the mass of a compact object is measured and exceeds 3 belong also to this set. It is *appreciably* greater than the mass of "usual" NS and least it is clear that the existence in Nature of such "supermassive" (>3 $M_\odot$) compac objects is incomprehencible in principle in the bounds of classic Newtonian gravitation. It should be noted here that discussions on a *precise* value of the upper limit for the mass of the compact object continue yet now. Here the estimation (3 $M_\odot$ is taken "with margin" though *non-newtonian* masses begin at a smaller value, bu >1.4 $M_\odot$.

If one does not identify *a priori the physics* of those "supermassive" (non-newtonian) objects with the physics of "black holes" of GR, i.e. independently of an philosophy, one speaks only about *observational manifestations* of such compact objects, then it is better to select them in a special *subset* (or a class) of object by use of an *intermediate* term. Here these objects are called *collapsars* as distinc from "candidates for black holes of GR", which is more frequent in literature. By us of the term "collapsar" I endeavour to be maximally objective with respect to an ideology, thus selecting the objects existing really in Nature, with real properties from properties of *the theoretical model* which are considered by many people as a *inevitable* result of corresponding experiments on *testing* the theory...

Thus, *purely observationally*, in the second set of objects whose physics can no be reliably identified with the physics of NS and white dwarfs, a small subset is distinguished of really existing objects of unknown nature, i.e. the collapsars. Her the objects with mass larger than 3 $M_\odot$ and which do not show apparently a pulsatin radiation can be included for sure. (Though the demand for the fulfilment of th last condition is needed in advance only in the absence of any doubts in GR...) *Th basic condition* here is that Newtonian theory is powerless for certain in descriptio of properties of so strong gravitational field of an object with a dimension of about its gravitational radius. At the collapsars mass about 6 $M_\odot$ the value of GM/c^2 is ~9 km.

By use of the term "collapsar" I want to emphasize also the fact that these objects were formed for sure as a result of a *relativistic* (non-newtonian!) gravitational collapse unlike NS (Newtonian collapse) and all the more unlike white dwarfs. In the end, the problem of origin of these "supermassive" objects is connected for sure with the problem of the supernova *explosion mechanism* ("collapse-anticollapse") which can lead to particularities in observational properties of the collapsars... In particular, may we be interested here, like the case of NS, in *binding energy* which *is discharged* at the moment of the collapsar formation?

If the big mass of the collapsar (>3$M_\odot$) is adopted as its *basic* sign, then the list of compact objects which are most interesting for the gravitation theory will include the following X-sources:

1) CygX-1. A famous binary system in which the mass of the companion invisible in the optics (compact X-source) is about $6M_\odot$ (see Shapiro, Teukolsky, 1983; Kopylov, 1986; Sokolov, 1987) and other determinations of the mass of CygX-1). The stable regular (periodic) pulsations of the X-flux which are typical of NS-pulsars were not detected reliably for the system. Though the records about possible *unstable* periods ("quasiperiodic oscillations" - QPO) emerge in literature from time to time (Kitamoto, 1989). And *aperiodic* variability of X-flux (flickering) of the object is strongly pronounced and the characteristic time here is of the order of $\Delta t_x = 1$ ms which testifies the minimal (i.e. *observed* in X-rays) dimension of X-source $\Delta l_x \geqslant c \cdot \Delta t_x \approx 300$ km... (The mass of the companion observed in optics in CBS CygX-1 is $(16\pm3)M_\odot$.)

2) A0620-00=V616Mon. This object was revealed in the list of objects which *are not* "usual" NS for sure comparatively recently (1986). More or less reliable interpretation of data of optical observations of the system testifies in favour of the following estimation of collapsar mass: $\approx 7M_\odot$ (McClintok, Remillard, 1986). (In the system the collapsar mass is 10 times greater than the optic star mass).

3) LMCX-3. This X-source in CBS is in a neighbour galaxy of the southern sky and may be a very possible candidate in collapsars. ($M_X \geqslant 6M_\odot$ (Cowley et al., 1987). (The optical companion is less massive here also: $3 \div 6M_\odot$.)

4) LMCX-1. The object is in the same galaxy as LMCX-3. The estimation of the possible collapsar mass is $(6\pm2)M_\odot$ (Hutchings et al., 1987). In the system a stable pulsar period was not found either, though a reliable quasiperiodic oscillation (QPO) of X-flux was found. The mass ratio in this CBS is approximately the same as in the system CygX-1.

A unique object SS433 could also be included in the collapsar list. But in the case the mass estimation of a *relativistic* object is too indirect since spectral lines of the normal star in the SS433 spectrum have not been selected reliably up to now and this, in turn, influences the mass estimation precision of its exotic companion...

3.CRUCIAL EXPERIMENT: THE HORIZON OR THE SURFACE?

For this or other reasons the collapsar masses are determined *worse* than the masses of NS (see Introduction). Here it could hardly be spoken about any "canonical" mass value, though the impression is that the masses of all the four "supermassive" objects are close to 6-7 $M_\odot$. More precise mass determination of such objects would be very important for the evolution problem of massive stars (the collapsar origin) and may be we could find out some *common properties* of collapsars ("an average collapsar").

Generally, more precise mass (and radius) measurement of compact objects (NS, QS, collapsars) gives us ultimately the possibility of judgement about the *matter state* at macroscopic densities of the order of ρ_{nucl} and more. The most precise determination of the compact object mass is the first step toward the determinatio of physical properties of dense and may be the densest objects. This is necessary no only for selection of collapsar candidates when rough estimations are sufficient fo the statement of the fact that $M_x > 3M_\odot$. If we assume that collapsars (like NS and QS) have, however, *the surface* (which is not excluded by observations), then a questio arises at once about the matter state equation of such compact and "supermassive" object. But for the time being the *upper limit* of the collapsar mass can be apparentl spoken about only in one case: that of CygX-1 ($5\ M_\odot < M_x < 9\ M_\odot$, (Sokolov, 1987). Her a lot is determined by the amount of acquired information about CBS with collapsars.

Besides, it should be emphasized that all the most reliable mass determinations of X-sources - objects with strong gravitational field - are made in "wave zone", i we use the terminology of the field theory here, or at distances much greater tha GM_x/c^2. Thus though we deal, for example, with the collapsar - a wittingly exoti *non-newtonian* object - its mass is determined, nevertheless, by Newton's law (automatically taking account also for "the coat", i.e. the gravitational field energy *above* the surface of the compact gravitating object).

In spite of the fact that the collapsar investigation problem was posed in the GR bounds (it is meant beforehand that there is no other theoretical alternative), th big ($>3M_\odot$) collapsar mass measurement alone (even at availability of X-radiation fro it) is not yet a crucial experiment allowing us to assert the correctness of identit

the black hole of GR $\overset{?}{\equiv}$ *the collapsar .(*)*

As was emphasized above, the big mass of the compact object is *first of all* the sig which puts such objects beyond the limits of Newtonian description of gravitation. Identity (*) will be true only if we are convinced (*experimentally!*) that the collapsar *physics* does coincide with the *physics* of a black hole of GR.

Thus unlike the situation that took place, say 15 years ago, *today* for compac objects (CygX-1, A0620-00, and other) selected by the big mass sign the result of th crucial (GR or not!) experiment can be presented as two possibilities:

1) If *the collapsar* shows reliably the signs of event horizon (or ergosphere then identity (*) is true and GR is true unconditionally.

2) But if *the collapsar* shows with the same reliability the surface signs (lik NS or QS) then GR really needs essential correction.

It should be kept in mind that in virtue of GR event horizon properties it becomes so subtle (for experiment) substance that its *discovery* is reduced ultimately t *undiscovery* (exclusion) of collapsar surface signs. It demands the most complete (al the signs?) knowledge of properties of objects which have the surface for sure (for example NS). That is just why the statement of correctness or incorrectness of identity (*) will be delayed for a long time yet...

At present the fact is realized more and more that the investigation of *signals* coming from regions with a *maximally* strong gravitational field is the crucial experiment, i.e. it is necessary to study as carefully as possible the *quickly changing component* of electromagnetic radiation which is formed *maximally close* to the collapsar. Here the interstellar matter falling onto the collapsar or the matter lost by the star-companion of CBS is the particles bombarding the collapsar, and X- and γ-radiation registered on the Earth is the signals. In particular, for CygX-1 X-radiation has the character of short ($\Delta t_x \approx 1$ms) flares - "explosions". Each flare discharges the energy of the order of 10^{37}erg/s$\cdot 10^{-3}$s $= \Delta Mc^2 = 10^{34}$erg. Thus, more than 0.2 of the mass of matter falling down from the neighbour star (at $\dot{M} \sim 10^{-9} M_\odot$/year) is transformed into X-radiation only...

But in spite of the fact that the X-source in the system CygX-1 is rather compact (>300km) it is *still far* (for $M_x = 6M_\odot$ approximately 10 times farther) from the crucial *dimension* $2GM_x/c^2 \approx 18$km where the most interesting for the theory region ($GM_x/c^2/R \approx 1$) with the strongest gravitational field is situated. We have to observe the events lasting 10^{-4}s and shorter to be sure that we see signals from this region namely. It is not excluded that *all* soft (kT~1-10KeV) X-radiation does not merge so deep, and it is γ-radiation (from 160 KeV to 9.3 MeV (McConnell et al., 1989) and even 700 TeV radiation (Kulikov et al., 1987) that will be a more quickly changing component of radiation observed from the system. In any case, shorter flares than $\Delta t \sim 1$ms have *not* been *detected* up to now from CygX-1.

If the black hole of GR is used as *the collapsar model*, then it excludes the regular variability of γ-, X-radiation (optics, radio). Since the black hole has no surface and sufficiently strong magnetic field (like NS), then it is *very hard* to create a nonuniformity ("spot") somewhere close to the event horizon which does not disappear for a long time... Ultimately it is a direct *observational* consequence of theorems about black holes and, in particular, "the theorem about the absence of hair" for black hole. Thus the *irregular* variability of X-radiation with a typical time of flickering of $2GM_x/c^3 < 10^{-4}$s must be a characteristic feature of accreting black holes. This is a variety of "crucial" test for the detection of black hole of GR! But it should be said that now the crucial character of the assertion is weakened to a certain extent because of the fact that like the NS case the magnetic field can be either "badly" oriented relative to a ground-based observer or too weak ($<10^9$Gs), or the collapsar is always a coaxial rotator... That is why it is desirable to have richer statistics of collapsars and dangerous to insist on "unique character" of the object.

The experiments searching for objects with *irregular* variability of optical radiation with a characteristic variability time of the order of 10^{-4}-10^{-5}s were undertaken for *the first time* at the 6-meter telescope by V.F.Shvartsman (Shvartsman 1977). In Shvartsman's experiment the question is on individual compact object accreting gas from interstellar environment. At a low luminosity (10^{-2} of solar luminosity) of the "halo" around such an object it can be seen at a distance of not mor than 300 parsecs. Thus for good statistics of such weak objects and detection o their variability a large telescope is needed. The experiments at the 6-meter telescope of the SAO have been taking place since 1974 and the result is so far the following: the objects showing variability on time scales from 10^{-4}s to 10^{-6}s near th Sun at distances less than 300 pc are not detected (Beskin et al., 1982). The neede (in GR bounds) irregular flares of the X-flux are not found either for 4 collapsar in CBS listed above. But as was mentioned above, the detection of these flares namel (in optics also!) does not exclude yet a possibility of pulsar period detection fo *new* members of the pulsar list...

All the above-mentioned allows us to select *regular pulsations* of γ-, X-, optica and radio radiation of objects as a reliable *evidence of collapsar surface*. This sig could be *sufficient* (but not necessary) for the exclusion of identity (*) since i the GR bounds it is impossible for sure to understand *millisecond* (and up t 10^{-4}-10^{-5}s) periods of (γ, X etc.) variability of compact ($R \approx GM/c^2$) objects with th mass of $6M_{\odot}$.

Recently besides the measurement of big mass ("weighing") of collapsars the stud of *spectrum* of the fast-changing component of radiation, i.e. of signals of "collision" of the accreting matter with the collapsar in CBS becomes more and more important. At such a "collision" an essential part of gravitational energy is released i the form of "soft" X-radiation in the inner parts of the so-called Kepler's *accretio disc* (the closest parts to the compact object) before the accreting matter finds itself near the surface (or the horizon) of the collapsar, NS or QS. In the case o CygX-1, ≈300 km is a lower limit and 11000 km is an upper limit of this "X-region" (estimations see in book (Shapiro, Teukolsky, 1983)).

Another contribution to the energy discharge (in γ-rays this time, not in X-rays, and may be even greater in value than the "disc" contribution) arises at direct *collision* of matter (bombarding particles) with the surface of the compact object i there is any... In such a case different types of *nonthermal* braking radiation ar possible because of sharp deceleration of falling (with the velocity of the order o $v_f \approx \sqrt{2GM/R}$) plasma and dissipation of its great kinetic energy ($Mv_f^2/2$ 10^{37}-10^{38}erg/s).

The collapsar could not have this latter "impact" component of energy discharge (luminosity) if it was the black hole of GR. In particular, *the spectrum of X-radiation* for black holes would be determined by the energy discharge in the accretio disc *only*, before the falling gas disappears under the event horizon. For this case (BH) the theory of disc accretion leads ultimately to two *observational* conclusions. The first is a *soft*, with the maximum near 1KeV, X-radiation. The second is a *shar* *"fall"* of the spectrum in the region of high energies ~100KeV, which is the result of Compton scattering on electrons in the inner disc regions closest to the compact object (Shapiro, Teukolsky, 1983).

The interpretation of observational results in X-range by disc accretion *only* (the horizon and there is no interaction with the surface!) met difficulties from the very beginning (Shapiro, Teukolsky, 1983)) in understanding of the hardest and *deepest formed* component of X-radiation (≳100 KeV) from collapsars. The needed "fall" of X-spectrum at high energies is simply *not observed.* The radiation from the "classical" system CygX-1 has been long and rather reliably observed at γ-telescopes in the range from 160 KeV to 9.3 MeV. (See the summary of observational data on γ-radiation from CygX-1 in (McConnel et al., 1989). The observations say about *variable* γ-radiation. In the case of 700-TeV radiation (Kulikov et al., 1987) the correlation is observed with the orbital period of CBS CygX-1. The problems are posed on study of fast and superfast variability of γ-radiation.

Thus, concerning the dilemma "the horizon or the surface" ("are black holes discovered?") it could be said that here, like in the case of fast brightness variability, the observations of hard radiation from CygX-1 (and other "candidates" also) *do not exclude the surface.* At least *now* it is so.

And what is more, in the hard "tail" of the CygX-1 X-spectrum we can see sometimes a detail which is very similar to an annihilation feature presenting as a rule in the spectra of most γ-ray bursters (Ling, Wheaton, 1989; Liang, 1986) and which is interpreted as a spectral line - a result of two-photon annihilation of e^- pairs on the NS *surface.* The spectrum analysis of 40 γ-sources shows that this line (511KeV) is shifted redward and the shift is equal to the value $z=(GM/c^2)/R=0.30\sim0.5$. It is the fast variability of the flux in the line and such large z that allow us to assume that we deal with the *surface* of the compact object (Mitrofanov, 1988) bombarded by e^- plasma being "cooled" on the surface. For comparison we note that if the annihilation occured at a distance of about 300 km from the center, z would be 18 km/300km≈0.06 only, at $M=6M_\odot$.

The data of γ-line observations in the spectrum of CygX-1 are not yet precise enough that we could speak on its red shift with the same precision as in the case of *40 sources* of γ-flares. But it is quite clear that such measurement could be a *direct test* on discovery of collapsar *surface.* On the whole, the big redshifts of *γ-spectrum* details could give an unambiguous answer to the question: is the signal formed "before the horizon" or "on the surface" (under the horizon)? At what depth are the hardest component in the spectrum of CygX-1 and the spectra of other collapsars formed? The discovery of *"superfast"* ($GM/c^3\approx10^{-4}$s and less) variability in annihilation and other γ-lines would be a crucial fact.

The aforesaid could be formulated in short in the form of one more *surface sign* for a compact object - collapsar. This is a *big redshift* ($z > 0.3$) of annihilation and other lines in *γ-spectrum* of such objects at a *superfast* variability ($<10^{-4}$s and up to 10^{-6}s) of radiation in these lines. At the collapsar mass ~$6M_\odot$ this is hardl understandable for sure in the bounds of GR, even if it is an irregular variabilit *only*.

Allowing for the fact that the question is *on the physics of only two-four* objects-collapsars, at present we can state the following. The absence of the neede "fall" in the X-spectrum of CygX-1, γ-radiation reaching 9 MeV (and may be even hundreds of TeV) and the presence of annihilation γ-line like for 40 objects (NS?) wit the surface *counterbalance chances* of both the adherents of discharge of energy "before the horizon" only and the adherents (not numerous!) of allowing for collisio with the surface. The latter corresponds to a "dissident" point of view of GR if w keep in mind that we speak about "forbidden" objects (CygX-1, A0620-00). However, i one proceeds from the total absence of any alternative to GR, then there is no sens in speaking about a crucial experiment.

4. THE MODEL OF A COLLAPSAR IN GRAVIDYNAMICS

4.1 The strong field, the bag + the coat

Thus the study of time behaviour of γ-radiation of compact objects and th measurement of red shift of annihilation and other γ-lines is *a direct way* of matte state study of these macroobjects. If we assume for the same 40 sources o γ-radiation (γ-ray bursters) for which $z=0.30\pm0.05$ that their masses are close t $1.4M_\odot$, then from the formula

$$z = \frac{\Delta\nu}{\nu} = \frac{GM/c^2}{R_\gamma} \approx \frac{(1.5\mathrm{km})\cdot M/M_\odot}{R_\gamma(\mathrm{km})} ,$$

the radius is equal to $R_\gamma=7(\pm1)$km, and for the mean *macroscopic* density of matter an *gravitational field* we obtain $\bar{\rho}\approx2\cdot10^{15}$g/cm^3, i.e. these are supernuclear densitie already ($\rho_{nucl}=2.8\cdot10^{14}$g/cm^3). And if we assumed (impossible in GR bounds) presen of a stable surface for collapsars with $M\approx6M_\odot$, then the measurement of big red shif ($z\geqslant0.3$) of annihilation γ-lines (certainly provided it is detected) would say abou *finite* ($>\rho_{nucl}$) mean macroscopic densities of matter and gravitational field fo these "supermassive" objects too.

In (Sokolov, 1989) a *totally nonmetric* model of gravitational interaction *gravidynamics* (GD) - was suggested as a possible theoretical alternative to GR (a other versions of *metric* description of gravitation). An essential feature of thi model is the presence of scalar component of gravitational field $\Psi=\eta_{ik}\phi^{ik}$, whe η_{ik}=diag(+1,-1,-1,-1) is a *unique* metrics which we shall use (a notation is the sa as in (Sokolov, 1989).

When adhering to a consistent *dynamic* treatment of gravitational interacti without drawing *any geometric* ideas, principles, analogies etc. beforehand, the problem of gravity field energy *must rank with* problems connected with energetics of other massless gauge fields (gluon one, photon one). In such an approach *the localibility of gravitons energy* and its sign (positive, of course) become such natural and *definite* notions as the localibility and the sign of energy of gluons and photons in experiments with strong and electromagnetic interactions. In exactly the same way these notions constituting the base of *any* dynamic description of field are tested in the case of *gravidynamics* in experiments (observations) with *strong* gravitational field when gravitational field energy density (θ_{00}) becomes close or even greater than $\rho_{nucl}\cdot c^2$. An essential feature here (unlike colliders experiments with big energy densities) is the fact that in the case of collapsars, QS and NS we deal with the same huge *but macroscopic* densities. Conformably, all the ideas of quantum massless gauge fields (gluons, photons) must be transformed for the case of *macroscopic* gravidynamics, i.e. the theory of *gauge* massless tensor fields of spins 2 and 0 for real gravitons and spins 0,0,1,2 (the whole set!) for virtual quanta of the "coat" around the collapsar.

Posing of the problem about collapsar in gravidynamics is considered in (Sokolov, 1989). A *nonstationary* process itself of a relativistic collapse should be understood here as a transition in a *bound* stationary stable state which resulted in a compact object with the radius of the region filled with matter up to $r_* \equiv GM/c^2$ and *total* energy (including gravitational coat!) equal to Mc^2. The process of relativistic spherically-symmetric collapse must be accompanied by the energy loss in the form of scalar gravitational radiation (the real gravitons of spin 0 are radiated), that is why *in gravidynamics* the Birkhoff' theorem is not correct. The possibility of experimental test of the scalar radiation impact in the CBS with radiopulsar PSR1913+16 is discussed in more details in (Sokolov, 1990a). A stable object which the collapsar is in gravidynamics (GD) (except the process of the collapse itself) is considered in (Sokolov, 1990). Below two theoretical models of collapsar are compared: GR-collapsar ("black hole" BH) and GD-collapsar (quark star QS).

GR-collapsar (BH) is first of all permanent collapse when the kinetic energy of compression is not transformed into anything. The black hole can *never* be considered a *bound* stationary object. The sphere of *absolute* instability i.e. the event horizon is the "BH surface". *The binding energy* of such an object becomes a hardly defined notion, though in GR one can define a gravitational deficiency of the mass of such "a body" as a black hole. But does this deficiency coincide with the binding energy, namely in the case of spherically-symmetric collapse? Because the binding energy is something that is *discharged* in some way at *binding* of an object, for example NS. And what can be "discharged" at the spherically-symmetric collapse of GR when Birkhoff' theorem is true just as other theorems on black holes? It should not be forgotten that here the question is on a relativistic stage of the collapse unlike NS. As Section 2 emphasized, the essential fact in formation of collapsars ($R \approx GM/c^2 \approx 9$km at

$M \approx 6M_{\odot}$) is just *the relativistic collapse*.

GD-collapsar. In the definition of a compact object model in GD one shoul proceed right (in my opinion) from the consistent *dynamic* definition of energy energy of gravitational field, energy localibility, etc... The GD-collapsar should b understood as *a result* of transition during a *finite* time of the order of $\sim GM/c^2/$ (i.e. a result of the relativistic collapse) in the *lowest possible* state of a gravitationally *bound macroscopic* object.

Since we proceed from dynamic principles, then GD-collapsar (like a quark o like an electron) must be a compound system. First of all this is a *macroscopic* "bag (QCD-bag?) containing particles and fields. The radius of the sphere (the bag) fille with matter for the collapsar - the object with lowest possible bound state - i equal to $R = r_* = GM/c^2$. The gravitational field in vacuum around the bag is "th coat" or continuous (from the point of view of macroscopic physics) *medium* or "th gas" of virtual gravitons. In gravidynamics (GD) the gravitational "coat" is a object with absolutely defined physical properties rather similar to properties o the coat around quark or electron. The basic feature here is the fact that in *macroscopic* GD we deal with *macroscopic* objects: the collapsar, bag, coat. Conformabl *macroscopic* characteristics of the coat but not quantum ones would be more appropriate here. In this case this is a tensor of energy-momentum of such a continuou (macroscopic) medium.

4.2. The strong static field, total mass M

In the spherically-symmetric case *in vacuum* around the bag the gravitationa coat properties are determined by the tensor of energy-momentum of "the gas" o virtual gravitons (Sokolov, 1989):

$$\theta^{ik} = \theta^{00}\cdot\mathrm{diag}(1, 1/3, 1/3, 1/3), \qquad \eta_{ik}\theta^{ik} = 0. \qquad (1)$$

In this case the energy density of gravitational field alone in such *"vacuum"*, i.e outside the bag with $R=r_*$, is equal to

$$\theta^{00} = \frac{1}{8\pi}\frac{GM^2}{r^4}. \qquad (2)$$

The relativistic gas of virtual gravitons, i.e. this gravitational "atmosphere"=coa consists of half of *scalar* and half of *tensor* gravitons. Conformably, for each component (partial densities and pressures) of such a gas one can write:

$$\theta^{ik}_{(0)} = \theta^{ik}_{(2)} = \frac{1}{2}\cdot\theta^{00}\cdot\mathrm{diag}(1, 1/3, 1/3, 1/3). \qquad (3)$$

The static spherically-symmetric gravitational field outside the bag is given by 4-tensor of potentials:

$$\phi_{ik}(r) = \frac{1}{f}\begin{bmatrix} \frac{GM}{r}(1 - \frac{r_*}{2r}) & 0 & 0 & 0 \\ 0 & \frac{GM}{r}(1 - \frac{r_*}{6r}) & 0 & 0 \\ 0 & 0 & \frac{GM}{r}(1 - \frac{r_*}{6r}) & 0 \\ 0 & 0 & 0 & \frac{GM}{r}(1 - \frac{r_*}{6r}) \end{bmatrix} \qquad (4)$$

Here $\phi_{ik}(r)$ is determined in inertial frame of reference in which a massive gravitating object *rests* in the origin of coordinates. Tensor $\phi_{ik}(r)$ describes *totally* the strong static field of the collapsar in vacuum if nonlinearities are allowed for (like QCD case) by a *finite* (only two!) number of corresponding Feinmann's diagramms (see formulae (6') in (Sokolov, 1989): $f\phi_{ik}\theta^{ik}_{(0)} + f\phi_{ik}\theta^{ik}_{(2)}$.

Here the *total* mass M of the object entering the determination of $r_*\equiv GM/c^2$ should be found in "longwave limit" (like classic charge of electron), i.e. at $r \gg r_*$ or, in other words, the mass is determined by Newtonian rules. And if the object is described by 4-potential (4) with the radius of the bag $R=r_*$, then M consists *by half* of the coat mass. Thus for the *total* energy (Mc^2) of GD-collapsar one can write:

$$\frac{1}{2}Mc^2(\text{the bag with } R=r_*) + \frac{1}{2}Mc^2(\text{the coat "in vacuum"}) = Mc^2. \qquad (5)$$

Thus, the GD-collapsar mass is determined by integration from its center ($r=0$) and up to $r=\infty$. Strictly speaking this is the *determination* of mass of *any objects* in GD. Due to this fact in GD there is no event horizon, that is ultimately the result of *total* refusal of geometric *phenomenology* constituting the base of GR. The bag surface can go under the sphere $r=2r_*=2GM/c^2$ as a result of the relativistic collapse, but the **whole** gravitating object including its gravitational "atmosphere"=coat can **never** be found under this "horizon".

4.3. The properties of the strong gravitational field

The properties of the strong static field of GD-collapsar in vacuum up to the sphere $r=r_*$ can be shown by use of an analogue of Newtonian potential corresponding to 4-potential (4):

$$\phi_{ik}(r) \rightarrow -f\phi_{00}(r) \equiv \varphi_N = -\frac{GM}{r}\left(1 - \frac{r_*/2}{r}\right). \qquad (6)$$

The behaviour of this function is shown in Fig. 1. In formula (6) r denotes the distance from the center to any point in vacuum, i.e. *over* or at least *on* the surface of the sphere filled with matter. The value of r is measured in *inertial* frame of reference where the gravitating spherically-symmetric object itself rests in the origi of coordinates, i.e. the value of r for the function (6) is *the same* both for an "infinitly removed observer" and for an observer on the bag surface. In Fig.1 r i measured in r_* units and φ_N in c^2 units.

A classical Newtonian hyperbola (-1/r in the same units, the curve "Newton") i shown as a "gauge" curve in Fig.1. It is well seen that when approaching the cente the GD-potential deviates to the left from the classical hyperbola because of th impact of gravitational field energy-tensions (1) distributed continuously around th bag. (For more details see in (Sokolov, 1989). The corresponding analogue of Newtonian potential in GR (GR curve $\ln\sqrt{1-2/r}$) must inevitably deviate from the "gauge hyperbola to the right for its derivative to turn to infinity in the point $r=2r_*$.

The value M at $r \gg GM/c^2$ means the same thing in all the three theories (GD Newton, GR) that is of course the result of correspondence principle. This is alway a "point" mass measured by usual astrophysical methods at $r \gg r_*$ or the mass in usua dynamic sense but not only a gravitational "charge".

In particular, when we emphasize the *static* character of the field around th bag for example with $R\approx r_*$, we mean always the existence of *classical limit* for th field of such an object as a *necessary* condition. If there is no such a limit fo some reason or other, for example at $R\to 1/2r_*$ when the whole object mass tends t become the field mass only, then in this case one cannot speak already about stati or stationary gravitational field of a "point" of the mass M. At $R\to 1/2r_*$ such macroscopic object ("the point") turns completely in gravitational waves. Hence w have the limitation for a too small (in comparison with $R=r_*$) dimension of the bag In other words, the emphasis of the static character of the collapsar field mean that such a system ("matter+field") is in a stationary stable state, when it does no radiate energy in the form of gravitational waves and *can* be characterized by definite "quantum" number Mc^2 or, at worst, such energy loss must be still sufficiently small in comparison with the *total* energy Mc^2.

For the force acting on a test particle with the mass $m \ll M$ we can write dow using GD-potential (6):

$$F = -m\frac{d\varphi_N}{dr} = -\frac{GmM}{r}\left(1 - \frac{r_*}{r}\right), \qquad (7)$$

if the test particle does not move very quickly and $v^2/c^2 \ll 1$ ($v^2/c^2=0.07$ at $v\approx 0.26c$) It is seen from (7) that at $r=r_*$ the force simply becomes zero. Correspondingly, i can be shown that the sphere $r=r_*$ is the sphere of particle minimal energy or *th sphere of stable equilibrium* in GD-potential (6) (point 1 in Fig.1).

Thus, vacuum potential (4) really permits the existence of the collapsar surfac at the bag radius of $R=r_*$, i.e. the bag boundary at $r=r_*$ can be in the state o stable equilibrium. It differs radically from what GR gives in the case (see Fig.1 when the forces at distances $r\approx 2r_*$ i.e. much earlier at *the same* M tends to inf nity in the *same* frame of reference.

GD, consistently allowing for the energy (or selfaction (6') $\phi_{ik}\theta^{ik}_{(0)} + \phi_{ik}\theta^{ik}_{(2)}$, see (Sokolov, 1989) of gravitational field, leads to a rather unusual result at $R=r_*$. Though we have here the object with a *strong* gravitational field over the bag surface ($\theta^{00} \approx Mc^2/R^3$) and nonzero force at $r>r_*$, but the bag surface itself is in the region of total equilibrium of gravitational forces. Upper layers of the bag do not press on lower layers at all, which differs from Newtonian gravitation. And GR asserts in general that the upper layers weight of contracting object always only increases at decrease of the object dimension with a given M. Conformably, both in Newtonian approximation and all the more in GR the hydrostatically equilibrium configurations of the type of NS or QS are possible only at those equations of state of their entrails which provide the stability in conditions of the strong (and utmost strong) pressure of upper layers on lower ones.

For GD-collapsar with the bag radius $R=GM/c^2$ the gravity is totally "switched off" and then the equation of state of this bag entrails must be *totally* determined by the inside matter properties. Such an object becomes "selfbound" approximately as it occurs with *strange* quark matter at small masses of "strange stars" considered in the bounds of "standard" approach to densest objects (Haensel, 1987).

In GD for the object with the mass M the sphere of *maximal* instability $r = r_{max} \equiv 1.5r_*$ (point 2 in Fig. 1) is the analogue of Shvarzshild's sphere (horizon = dotted line in Fig. 1) - the sphere of *absolute* instability in GR. Corresponding *maximal* (for given M) gravity acceleration on the sphere is

$$g_{max}\Big|_{r=r_{max}} = -\frac{4}{27}\cdot\frac{c^4}{G}\cdot\frac{1}{M}\,. \tag{8}$$

From the GR point of view this formula is a total absurdity since it asserts that it is possible (under the event horizon!) to obtain any given *small* g_{max} by merely *mass increase* of gravitating object. For example, for a body with the mass (at infinity!) equal to $7\cdot 10^{10} M_\odot$ and the radius of $r=r_{max}=1.6\cdot 10^{15}$ cm$\approx$10a.u. the acceleration of the surface ($r=GM/c^2\cdot 1.5$) is not greater than the gravity acceleration on the surface of *usual* star. And the mean density is a thousand times less than the mean density of stars. Such a star cluster (though *compact* one: $R>1.5r_*$ or R of the order of $1.5r_*$) at rather small inner "antipressure" has no reason making it "to burst" to utmost bound states at a given mass M, when $R=GM/c^2$. Inner interactions determining "the equation of state" (temperature, pressure, dispersion of star velocities, rotation moment in hierarchical systems, etc.) for stars of such a cluster compete here quite well with such a gravitation.

On the other hand, *at small masses* $M{\sim}6M_\odot$ the maximal acceleration (8) becomes huge, $g_{max}=1.6\cdot 10^{14}$ cm/s^2, as on NS surface, and more. In this case the mean density is equal already to $\bar{\rho} \approx \rho_{NS} = 6.7\cdot 10^{14}$ g/cm^2. The acceleration will increase more if this object "gets cold" in some way (with radiation of neutrinos, for example) and owing to that so decreases its mass that it loses stability, and the fall during the ti $\sim r_*/c$, "the burst", the collapse with (even greater) loss of initial total ener $M'\cdot c^2$ for gravitational radiation become possible. I.e. the relativistic collap proper in absolutely bound lowerest possible state will become possible. The colla sar with the bag radius $R=r_*$ and mean density not less than several nuclear on is formed as a result of such a *relativistic* collapse. One may assume that at su densities the matter of collapsing body (NS?) turns out to be in the state of quar gluon plasma (QGP) as a result of the relativistic collapse with the radiation (scalar gravitational waves. Thus, the relativistic collapse in GD realizes the pha transition "hadrons → quarks" in the macroscopic volume of the bag.

5. CONCLUSION. GRAVITATIONAL HIGH ENERGY PHYSICS

Of course, everything stated in Section 4 is perceived first of all as a *proje* (one more!) of GR improvement though at the cost of total giving up any geometr phenomenology. But when formulating the "project" in (Sokolov, 1989; 1990; 199 1989) we endeavoured to proceed not only from the condition of precise description (all the "old" experiments in weak gravitational fields (Sokolov, 1988; 1980). Our a was ultimately the description of *observational* particularities of strong gravi ational field of compact objects (see Section 2,3) and the obtaining of concrete *nu* *bers* describing such experiments. We proceeded from the idea that it is not t choice of some Lagrangian of the theory but the *ultimate result* of such a choice new observational effects - must be the essence of projects of the kind.

Thus, GD suggests a GD-collapsar - an object with the surface as a possib alternative to black hole in identity (*) if it is not true however. Apparently, t GD-collapsar is the object with an *utmost* strong or utmost permissible by the rest the physics gravitational field of a macroscopic compact object. The energy densi of the field (see (2)) θ^{00} on the bag surface ($R=GM/c^2$) achieves several nucle ones ($\theta^{00}>\rho_{nucl}\cdot c^2$). Inside the bag the matter density increases continuously towa its center by the law ~1/r. As a result the matter turns out to be *on the whole* the state of quark-gluon plasma (QGP).

The precision with which the parameters of the phase transition "hadrons quarks" (QGP-transition) are known at present allows us to estimate the mass of t GD-collapsar. If the phase QGP-transition occurs at densities equal to 4÷2 nucle ones then the mass of the GD-collapsar is in the range of $(4.7\div6.7)M_\odot$ and the b radius (GM/c^2) is not greater than 10 km.

Such an object is a two-phase system. *The first phase* is the bag itself, who matter is totally in the phase of QGP. *The second phase* is the gravitational field vacuum, the "atmosphere" of virtual gravitons (tensor and scalar ones), the co "*laying*" on the bag surface. Thus the GD-collapsar is a limit macroobject who gravitational field is *totally* "pressed out". This field *does not interact* longer with the bag matter since the "mean free path" of scalar and tensor gravitons is equal to the bag size and at gravitons energy density of $\theta^{00}>(4\div 2)\rho_{nucl}\cdot c^2$ in such "vacuum" they interact ($\psi_{ik}\theta^{ik}_{(0)} + \psi_{ik}\theta^{ik}_{(2)}$) already with each other only, i.e. outside the bag...

Thus, GD-collapsar must be *a quark star*. But unlike quark (strange) stars considered in (Haensel, 1987; Krivoruchenko, 1987) on the basis of "standard" hydrostatics equations by Oppenheimer-Volkov where the properties of gravitational coat are not allowed for at all, the bag hydrostatics on the basis of equation (7) ("under the horizon") at density $\varepsilon(r) \sim 1/r^2$ increasing toward the center gives a quark star consisting not only of light (u,d,s) quarks. If outside vacuum the field is given by formulae (1)-(4) then *inside* the bag the total density of QGP (particles+fields) continuously increases toward the center by the law:

$$\varepsilon(r) = \frac{1}{8\pi}\cdot\frac{c^4}{G}\cdot\frac{1}{r^2} \quad , \tag{9}$$

where $0<r\lesssim 10$km at the total collapsar mass $< 7M_{\odot}$. In such a case the strange matter can be situated only near such a bag surface (where $\varepsilon \approx (2\div 4)\rho_{nucl}\cdot c^2$), and at the density increase toward the center the matter will consist of more and more heavy quarks (u,d,s,c,b,t, ...).

Finally, besides the mass of such a quark star ($\sim 6M_{\odot}$) and the bag size $\lesssim 10$km, one can speak also about other *observational limitations* following the abovementioned.

1) Stable equilibrium (in point 1, see Fig.1) at $R=r_*$ for potential (6) allows us to assume the possibility of *periodic* pulsations of the bag *surface* with $R\leqslant 10$km, whose frequency is $(r_*/c)^{-1}= c/10$km $= 33.3$ kHz and more ($r_*/c \approx 3\cdot 10^{-5}$s). The observational detection of so high-frequency regular oscillations for compact objects-collapsars is a reliable sign of their surface (see section 3).

2) The limit value of difference of gravitational potentials (see Fig.1) between the surface and a point in infinity is equal to $\varphi_*=-c^2/2$. Ultimately it leads to the fact that *the rest mass* of a *bound* test particle decreases (analogously to the quark mass in chromodynamics) in potential (6) and on the sphere $R=r_*$ it is two times less ($m_*=1/2\cdot m$) than the mass of the same particle in infinity. Correspondingly, the redshift of spectral lines, for example, of the line of two-photon electron-positron ($m=m_e=0.511$keV at $r\to\infty$) annihilation on *the surface* with $R=r_*$ must not be greater than $z=0.5$. Thus, the collapsar, according to GD, must not be "black" at least(!), if it does have the surface. And the detection of so big $z=0.5$ (see Section 3) by stationary details of spectra could testify in favour of *relativistic* collapse experienced by the compact object with the mass $\sim 6M_{\odot}$.

The notion of properties (the mass, the radius, z, etc.) of utmost bound compact object in the bounds of GD demands the allowing for other interactions besides gravitational one. (Whereas the black hole of GR is "scale invariant" one). Quark sta properties in GD are determined ultimately by matter properties in QGP. On the on hand, the study of these properties is the main aim of colliders (of the type of LHC experiments on the collisions of hadrons, heavy ultrarelativistic ions, etc. And o the other hand, the study of matter properties at so big *macroscopic* densitie demands inevitably the allowing for its gravitational properties neglected by physicists, i.e. the question can be on *QGP-properties in astrophysical conditions*, whe experimental investigations of the strong gravitational fields (the mass measurement, high-frequency brightness variability of collapsars, the measurement of z of γ-lines, etc.) can precise directly both the parameters of the phase QGP-transition and mas values of heavy quarks, and (probably!) can solve the problem of H-boson etc. Thu the question really can be on gravitational high energy physics.

Thus, the suggested "project" means the movement to *almost* the same aims in th investigation of properties of utmost compact (and utmost dense) objects, which wer formulated in the bounds of GR. In particular, for GD (like GR) the experimental (observational) investigations of the same objects - candidates for black holes of GR - remains urgent. But instead of identity (*) (in Section 3) GD suggests an alternative:

$$\text{the quark star} \overset{?}{\equiv} \text{the collapsar.}$$

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