Do blackholes and blackhole evaporation have TGD counterparts?

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Abstract

The blackhole information paradox is often believed to have solution in terms of holography stating in the case of blackholes that blackhole horizon can serve as a holographic screen representing the information about the surrounding space as a hologram. The situation is however far from settled. The newest challenge is so called firewall paradox proposed by Polchinsky et al.

These paradoxes strengthen the overall impression that the blackhole physics indeed represent the limit at which GRT fails and the outcome is recycling of old arguments leading nowhere. Something very important is lacking. On the other hand, some authors like Susskind claim that the physics of this century more or less reduces to that for blackholes. I however see this endless tinkering with blackholes as a decline of physics. If super string had been a success as a physical theory, we would have got rid of blackholes.

If TGD is to replace GRT, it must also provide new insights to blackholes, blackhole evaporation, information paradox and firewall paradox. This inspired me to look for what blackholes and blackhole evaporation could mean in TGD framework and whether TGD can avoid the paradoxes. This kind of exercises allow also to sharpen the TGD based view about space-time and quantum and build connections to the mainstream views.

1 Introduction

The blackhole information paradox is often believed to have solution in terms of holography stating in the case of blackholes that blackhole horizon can serve as a holographic screen representing the information about the surrounding space as a hologram. The situation is however far from settled. The newest challenge is so called firewall paradox proposed by Polchinsky et al [7]. Lubos Motl has written several postings about firewall paradox and they inspired me to look the situation in TGD framework.

These paradoxes strengthen the overall impression that the blackhole physics indeed represent the limit at which GRT fails and the outcome is recycling of old arguments leading nowhere. Something very important is lacking. On the other hand, some authors like Susskind claim that the physics of this century more or less reduces to that for blackholes. I however see this endless tinkering with blackholes as a decline of physics. If super string had been a success as a physical theory, we would have got rid of blackholes.

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2 Background

2.1 Hawking radiation and information paradox

A theoretical argument supporting the existence of Hawking radiation from blackhole was suggested by Hawking in 1974. Before this Bekenstein had proposed that blackhholes are characterized temperature and entropy. The implication is that blackholes radiate their mass gradually as thermal radiation. Since thermal radiation carries no information, this leads to black hole information paradox if one assumes that the blackhole evolves unitarily.

Hawkings's original conclusion - which he later gave up - was that information is indeed lost. Susskind and t'Hooft proposed holographic principle stating that the information is actually contained in the radiation emitted from the blackhole. There are several approaches to the information paradox: information is destroyed, information gradually leaks out, information suddenly escapes in the final states of evaporation, or is stored in Planck sized remnant. Basic assumptions have been Equivalence Principle and unitary of the emission process of blackhole evolution. Penrose's disagreed about the necessity of assuming unitary evolution: state function reduction is non-unitary process and his proposal was that gravitation induces state function reductions.

2.2 Firewall paradox

The firewall paradox was introduced by Polchinski et al One considers two observers: distant observer and observer falling in late stage blackhole. If one assumes both Equivalence principle in the sense that M^4 QFT applies in low curvature regions (therefore also somewhat below the horizon) and requires unitary of emission of Hawking radiation, one ends up with the prediction that falling observer must encounter a firewall at horizon (quite concretely destroying her) or there is new nonlocal long length scale dynamics involved. EP however predicts that no such firewall should be encountered since low curvature regions are in question and M^4 QFT should work. Therefore unitary and EP lead to conflicting predictions.

In the following Bob refers to distant observer and Alice is the observer jumping into blackhole. The core of the argument goes as follows.

1. Bob: Unitarity requires maximal entanglement BR, R early Hawking radiation. If one assumes that entanglement matrix is unitary or product of projection operator and unitary matrix then this is the case but I do not quite understand why this should be the case.

2. Alice: Horizon approximated by Rindler wedge [6, **?**, 2]. Minkowski vacuum superposition of state pairs at different sides of the Rindler wedge. Nearly maximal entanglement for Minkowski vacuum represented in terms of states associated with the right and left wedges is easy to understand. EP requires maximal entanglement BA, A inside blackhole. Therefore B is maximally entangled with both A and R. This is contradiction by the monogamy of maximal entanglement (more precisely with the sub-additivity of entanglement entropy).

There has been an intense debate about the firewall paradox. For instance, Bouzzo has written two articles with different conclusions.

Bouzzo's first article has title Observer complementary resolves firewall paradox [5]. The argument goes as follows. By EP Alice falling in blackhole can approximate local physics in low curvature regions by the physics in empty Minkowski space: the region above and also somewhat below horizon is low curvature region. Blackhole looks like membrane for Bob. Alice observers no membrane. Therefore the descriptions of the two observers are inconsistent. Observer complementarity is claimed to save the situation. Observers are not able to communicate to each other their contradictory findings concerning the existence horizon, and therefore cannot discover the inconsistency. The measurements of Alice and Bob are analogous to measurement of non-commuting observables. These are to my opinion lawyer arguments. Laws of physics could be violated when no-one is seeing it!

Bouzzo's second article is titled Observer complementarity is not enough [4]. The new argument developed by Bouzzo states that Alice can actually gather information about the existence of horizon and avoid falling into blackhole and therefore communicate the information to Bob so that paradox becomes observable.

To my opinion observer complementary and blackhole complementarity suggested by Susskind [**?**] and involves the assumption of stretched horizon with thickness of Planck length sound questionable hypothesis.

3 About basic assumptions about blackhole evaporation as seen in TGD context

1. For GRT blackholes the interior does not allow geodesic lines to escape to blackhole exterior: in other words the escape velocity is larger than light velocity. Also the roles of time coordinate and radial coordinate are exchanged.

   In TGD sub-manifold gravity leads the replacement of blackhole interior with an Euclidian region [1]. Motivation for this comes from the study of small perturbations of the Reissner-Nordström metric transforming horizon to light-like 3-surfaces and making 4-metric degenerate at horizon so that Euclidian metric signature becomes natural in the interior. This leads to a new view about the microscopic origin of cosmological constant: there are actually many manners to interpret cosmological constant and the recent progress in the understanding of preferred extremals predicts Einstein's equations with cosmological constant which - like also Newton's constant- can in principle depend on extremal [5].

   Horizon property is preserved since nothing can escape from Euclidian region to Minkowskian region. The reason is that in Euclidian region the square of four-velocity is negative and in Minkowskian region positive or zero unless a tachyon is in question. Note that the 4-metric becomes degenerate at horizon in time direction. Minkowskian QFT description inside TGD blackhole is definitely lost. As a matter of fact, it seems that any physical object by definition corresponds to a system with horizon in which the signature of the induced metric changes. One can also say that any physical object can appear as a line of generalized Feynman diagram understood as Euclidian space-time region whose M^4 projection can be arbitrarily large. Blackholes would be replaced with a much larger variety of objects with horizon to which an appropriate generalization of the ideas of blackhole physics might apply. This would represent TGD counterpart for AdS/CFT correspondence with AdS replaced with space-time surface and conformal field theory assigned with light like 3-surface and partonic 2-surface and tangent space data by strong form of holography.

2. The assumption about fixed space-time might be unacceptable in the case of blackhole even in the length scales of order Schwarzschild radius.

   In TGD framework the notion of many-sheeted space-time leads to the hierarchy of effective Planck constants [2]. This hierarchy suggests that black holes could be macroscopic quantum systems. In particular, the degrees of freedom associated with the "world of classical worlds" (WCW) could not be approximated as being frozen anymore so that QFT description would fail. Even outside the blackhole the presence of magnetic flux quanta suggested to mediate gravitational and also other interactions [4] brings in new highly non-trivial essentially non-local degrees of freedom.

3. In GRT framework EP is assumed in the form that M^4 QFT describes physics locally in the low curvature regions, and applies also below horizon as long as curvature is not too large.

   In TGD framework this form of EP need not make sense in TGD, and certainly not so at the boundary of Minkowskian and Euclidian regions defining the TGD counterpart of blackhole horizon. EP as Einstein's equations makes sense in TGD although the equations do not follow from a variational principle but as a property of preferred extremals guaranteeing a generalization of 2-D conformal invariance to 4-D context. Gravitational constant and parameter Λ are predictions of classical theory rather than inputs.

4. Blackhole thermodynamics suggests that information about the state of matter collapsed into blackhole is lost. This leads to blackhole information paradox [1].

   The Unruh effect [3] (see the article article [6] suggests a possible solution to the problem.

   (a) Consider a system accelerated with constant acceleration a. A convenient coordinate system is $M^2 \times E^2$ such that acceleration in M^2. The coordinates for M^2 are 2-D variant of Robertson-Walker coordinates: $(t, x) = a(sinh(\eta), \pm cosh(\eta))$, where $\pm$ corresponds to the two disjoint components L and R of the set $t^2 - x^2 < 0$ of M^2. The orbit of the accelerated system correspond to the $a = constant$ hyperbola with a proportional to the inverse of acceleraton. At the limit of infinite acceleration one obtains orbit at the boundary of 2-D light-cone defining Rindler horizon [2].

   (b) For an accelerated observer it is natural to quantize field theory in the right wedge R and the vacuum of full M^4 QFT is sum over products of state in L and R. For large values of acceleration these states have nearly maximal entanglement. The tracing over L or R yields thermal density matrix with temperature equal to $a/2\pi$, a the acceleration.

   (c) The analogies with blackhole horizon are obvious, which leads to the idea that Hawking radiation is like Unruh radiation and Hawking temperature is analogous to Unruh temperature. The problem is that speaking about acceleration in Minkowski space in GRT, where geodesic motion corresponds to a vanishing acceleration, does not seem to make sense.

   TGD can be seen as sub-manifold gravity and this changes the situation. The geodesic lines at space-time surface are not geodesic lines of the imbedding space, and therefore have non-vanishing trace of second fundamental form as curves of imbedding space rather than space-time surface. The M^4 part of the second fundamental form defines acceleration. What is also intriguing that $M^4 = M^2 \times E^2$ decomposition appears in quantum TGD at fundamental level having both purely physical and number theoretical justification. Could this decomposition define also the analogs of Rindler wedges and Unruh decomposition? Could one see the TGD counterpart of Hawking gravitation as a "kinematic effect" very much analogous to Unruh radiation?

5. Blackhole time evolution is assumed to be unitary and Hawking evaporation is assumed to be a unitary process.

   In TGD M-matrix replaces S-matrix and M-matrices define the rows of unitary U-matrix. Quantum dynamics can be seen as a sequence of quantum jumps to which one can assign state preparaton, state function reduction and unitary process. At ensemble level (for sub-CDs of CD) one has dissipation and blackhole like system is like any other macroscopic quantum system. There is also hierarchy of space-time sheets and small space-time sheets defined dissipating ensembles. The entire system however behaves unitarily. In reality one must take also the interactions of blackhole with environment into account so that exact unitary holds only for this system.

   In TGD based quantum theory state function reduction (describe in more detail in the chapter About the Nature of time [1] is the basic element of quantum dynamics. One has sequences of unitary evolutions followed by state function reductions. TGD space-time is many-sheeted so that these evolutions appear in many scales characterized by the size scales of causal diamonds (CDs). In the scale of CD assignable to blackhole the time scale characterizing the unitary evolution at the space-time sheet of blackhole is certainly very long so that unitary at this space-time sheet should be a good approximation. For small sub-CDs situation changes and one can assign the ensembles formed by them growing entropy.

6. In quantum gravity Planck length scale is often assumed to be something fundamental. This could quite well be an illusion produced by dimensional analysis.

   In TGD framework CP_2 length scale which is of order 10^4 times Planck length scale defines the fundamental length scale with concrete geometric interpretation and Planck length scale emerge only as formal scale which need not have any geometrical correlate.

4 Relating the terminology of blackhole evaporation to TGD framework

It is useful to consider the terminology related to blackhole, black hole evaporation, and entanglement from TGD point of view.

4.1 Blackhole and observers

1. *Horizon*: the surface inside which the escape velocity for particles larger than c. Time coordinate and radial coordinate change their roles. For the imbedding of Schwarzschild metric in $M^4 \times CP_2$ this happens quite concretely.

   In TGD interior of blackhole like state has Euclidian metric and the boundary between Minkowskian and Euclidian regions acts like a causal horizon.

2. *Stretched horizon*: Horizon replaced with a layer of thickness Planck length.

   This notion could has a counterpart in TGD although the scale in question is much larger than Planck length. Particles just outside the TGD horizon as wormhole contacts connected by magnetic flux tubes to the horizon which is very large wormhole contacts as far as M^4 projection is considered.

3. *Rindler wedges*: Blackhole horizon approximated as Rindler horizon in GRT. One approximates the situation using QFT in $M^4 = M^2 \times E^2$ where M^2 has hyperbolic coordinates motivated by the fact that the orbit of particle with constant acceleration is hyperbola. Minkowski vacuum in the accelerating system described by right Rindler wedge is seen as almost maximally entangled state in tensor product of the two sides of the wedge. In GRT framework this approximation is questionable since acceleration is questionable notion: it vanishes for geodesic lines.

   What about TGD?

   (a) In TGD framework blackhole horizon cannot be approximated as Rindler horizon since the interior of TGD blackhole is Euclidian. What is how intriguing that $M^2 \subset M^4$ inclusion appears in TGD framework in key role. Also Rindler wedge involves preferred M^2 determined by the direction of acceleration. The trace of the second fundamental form defines acceleration like variable for any sub-manifold and for 1-D curve in particular. Only the right Rinder wedge is realized as Minkowskian region at wormhole throats. Therefore it does not make sense to speak about Unruh effect and Hawking radiation at horizon since Minkowski vacuum is not a sensible approximation here.

   (b) Generalized form of holography however suggests that horizon is mathematically and physically equivalent with any parallel light-like 3-surfaces forming a slicing around the horizon. For them Rindler wedges make sense and one would obtain the analog of Hawking radiation as Unruh effect.

   (c) Rindler edges could be also interpreted as outside of the CD and the motion of particle in this region as motion in gravitational field created by matter outside CD. CD resembles blackhole at the level of imbedding space. Outside has also interpretation in terms of interior of another CD.

4.2 Entanglement

There are some notions related to entanglement. Purifying entanglement for density matrix of system B means existence of a system R_B such that $R_B B$ is pure - in other worlds the density matrix of B is obtained by tracing over R_B.

Almost maximal entanglement means that the density matrix of second entangled system obtained by tracing is in near unit matrix. The monogamy of maximal entanglement states that a given system cannot have maximal entanglement with to disjoint systems is the core of the argument leading to the firewall paradox.

Alice is argued to see a mirror system inside horizon maximally entangled with Bob: $A\heartsuit B$ in the notation half-jokingly introduced by Lubos Notl who seems maximal entanglement as love (personally I prefer see negentropic entanglement as correlate of love and various kinds of positive emotions such as experience of understanding).

4.3 Hawking radiation

Early radiation R and late radiation R' are assumed to combine to form a pure state RR', which is maximally entangled. If a unitary matrix multiplied by a projection operators to R and R' (P_1SP_2) defines the entanglement coefficients, maximal entanglement is obtained.

What could this correspond in TGD? ZEO implies that density matrix is replaced with M-matrix defining time-like entanglement coefficients. M-matrix as counterpart of S-matrix is not unitary. Unitary matrix U however exists and has M-matrices as its rows. Quantum evolution is a sequence of quantum jumps reducing to state function reductions at the upper and lower boundaries of CD. Unitary evolution relates to each other the two basis of zero energy associated with opposite boundaries. These differ in that positive/zero energy part of state is prepared whereas the second part of state is superposition of states with different particle numbers and with ill-defined single particle quantum numbers.

5 Could blackhole evaporation have a TGD counterpart?

Basically any burning process is analogous to blackhole evaporation in TGD framework sinceEuclidian region defines a space-time counterpart for a system in any length scale. Blackhole is different only because the gravitational field outside horizon is so strong that its stability with respect to small perturbations forced the generation of Euclidian region. This is enough to explain what we can observe about blackholes.

5.1 TGD counterpars of blackholes

In TGD based on ZEO the description of the TGD counterpart of blackhole looks different.

1. The TGD counterpart of blackhole is described by zero energy state to which one can assign a CD. At imbedding space level of CD is very much like horizon since the induced metric is degenerate. The region outside CD is like Rindler wedge for $M^2 \subset M^4$. For sub-CDs these wedges would look natural and gravitational field could correspond to that created by sub-CD. Therefore it seems that horizons are obtained both at imbedding space level and space-time level.

2. Wormhole throats are counterparts of black hole like states at space-time level. Blackhole horizon is replaced by horizon at which the induced metric becomes Euclidian. This horizon is also a causal horizon: nothing leaks from the interior since 4-metric becomes degenerate at the horizon. One cannot anymore apply Rindler wedge argument at the horizon and the argument that Alice sees a state in which blackhole interior and distant observer are maximally entangled is lost. One gets rid of firewall paradox since one does not anymore have maximal entanglement of same system B with two different systems.

3. Strong form of holography holds true. Partonic 2-surfaces and their 4-D tangent space data (string world sheets) code for physics. Generalized blackhole horizon can be said to carry the matter. Particles can condense around horizon. Elementary particles correspond to structures involving wormhole contacts connected by Minkowskian magnetic flux tubes at parallel space-time sheets and combining to form a closed magnetic flux tube. The wormhole contact at the second end of the flux tube can attach to the horizon. This gives rise to a real firewall [3], and the simplest model for blackhole would be as this kind of hollow spherical structure. The topology

of Euclidian region can be more complex than that of the interior of sphere since wormhole flux tubes with Minkowskian signature can be present in interior.

4. The interior of the ordinary blackhole can be isolated from the external world. In TGD framework one cannot assume this. Magnetic flux tubes can connect the wormhole contacts associated with particles very near to horizon and horizon itself to distant system. Gravitational and also other interactions are mediated along this kind of flux tubes and make possible for black hole to exchange energy with external world. At the microscopic level the description in the case of fermions (right handed neutrino is an exception) reduces to ??string world sheets at which the fermionic modes are localized [5] by very general arguments. Hence the analog of AdS/CFT duality is realized.

5. The exterior of TGD counterpart of genuine blackhole like in general relativity apart from imbedding to $M^4 \times CP_2$. Also the interior of blackhole allows imbedding down to some critical radius. At horizon, where $g_{tt} = 1/g_{rr} = 0$ holds true, a small deformation of g_{rr} makes the horizon a light-like surface and 4-metric degenerate. Hence it is natural to assume that blackhole interior has Euclidian metric in TGD framework. In the simplest case matter resides very near to the causal horizon which is now light-like 3-surface at which space-time surface is effectively 3-dimensional metrically. Approximation by Minkowskian physics certainly fails at horizon and below it. The argument leading to firewall paradox is lost.

6. In TGD framework evolution by quantum jumps realized as state function reductions is a key element of quantal evolution. Also blackhole evolution takes place as a sequence of quantum jumps between zero energy states assignable to light-like boundaries of causal diamond (CD) accompanying blackhole. Therefore loss of information is not a problem. TGD view about quantum jump leads to a rather radical revision of views about the relationship between geometric time and experienced time as well as about the notion of arrow of time already characterizing zero energy states in the sense that positive/negative energy state at upper/lower boundary of CD is prepared and the state at opposite boundary is superposition of states with different particle numbers and ill defined single particle quantum numbers.

7. Density matrix is replaced by M-matrix defined as a product of a hermitian square root of density matrix and unitary S-matrix. M-matrices form rows of unitary U-matrix. Square root of thermodynamics. The series of state function reductions thermalizes ensembles. Subsystems consisting of sub-CDs become thermal ensemble. CD itself can be said to evolve unitarily at the level of U-matrix. If density matrix is projection operator, then maximal entanglement is obtained between positive and negative energy states.

5.2 Could TGD counterparts of blackholes evaporate?

Could TGD counterparts of blackholes evaporate?

1. One could see the most general TGD counterparts of blackholes as ordinary macroscopic bodies with the space-time sheet representing the object having Euclidian signature of metric in the space-time region defined by the body. As noticed, this region can be topologically a sphere with handles represented as Minkowskian wormholes connecting separate parts of spherical horizon. Therefore the analog of thermal radiation would make sense. Hawking evaporation poses much stronger condition. Elementary particles represent limiting cases of Euclidian regions and electron is stable against decays and also against evaporation of this kind. General TGD blackholes need not have any special gravitational properties. In the case of genuinely blackhole like states, one can also restrict the situation so that the exterior metric is Reissner-Nordström vacuum in good approximation.

2. An attractive manner to interpret Hawking evaporation in the standard framework is by approximating the horizon by Rindler horizon. This leads the study of effectively 2-D Rindler wedge in Minkowski space assignable to accelerated system. The two sides of the wedge correspond to their own Rindler vacua and Minkowski vacuum is sum over pairs of states at both sides so that one obtains thermal spectrum of particle states with Unruh temperature. Accelerated observer would be continually boosted so that the hyperbolic angle η would grow. Accelerated observer would see Hawking radiation.

Does it make sense to speak about accelerated observers at fundamental level? The following little argument suggests that one cannot speak about Hawking radiation at horizon. This conforms with the intuitive idea that Hawking radiation is created outside the horizon.

1. One can assign to each point of space-time surface a generalization of acceleration vector as M^4 part of the trace of second fundamental form. For preferred extremals the trace of the second fundamental form would actually vanish since they are minimal surfaces.

   One can also consider second fundamental form for curves - say geodesics. This has both M^4 and CP_2 parts and does not vanish in general. The orbit of the boundary of string world sheet along light-like 3-surface is one possible identification. Braid strands, which can be both time-like and space-like, could be seen as analogs of accelerated observers with acceleration defined by M^k. The decomposition $M^4 = M^2 \times E^2$ with Rindler coordinates and Rindler decomposition of the M^4 vacuum at each point of the curve would give one further function for $M^2 \subset M^4$ dictated by several general arguments.

2. At the horizon of TGD blackhole the metric changes to Euclidian. Also the dimension of M^4 projection becomes at most $D = 3$ if the proposed general solution ansatz for preferred extremals is correct [5]. Hence the description as Rindler horizon and the approximation by M^4 QFT fails at and below the horizon. This is counterpart for the firewall. This holds true for all braid strands defining orbits along wormhole throats. For space-like string curves situation is different but now a tachyon would be in question. Hence one cannot speak about Unruh radiation and Hawking radiation at horizons and below them.

Could one generalize the notion of hologram from wormhole orbit so that Hawking radiation would result as Unruh radiation? This is possible to imagine.

1. One can consider a slicing of space-time sheet by "parallel" light-like 3-surfaces in the vicinity of given wormhole throat. If it is possible to make measurements at these light-like 3-surfaces, one could have QFT in M^4 as an approximation and have Rindler decomposition, Unruh effect, and Hawking radiation beyond Schwarzschild radius r_s.

2. In WCW geometry strong form of GCI implying strong form of holography suggests that any choice of light-like 3-surface in a slicing of space-time sheet by light-like 3-surfaces is equally goo , and means only a transformation of the Kähler function of WCW by adding to it a real part of holomorphic function induced gauge transformation of Kähler gauge potential of WCW. This does not affect WCW metric and should not affect physics either. Wormhole throats would be of course in a preferred position physically.

3. More precisely, at the wormhole throat the vacuum state is right Rindler vacuum R. At larger distances Minkowski vacuum makes sense approximately and is in reasonable approximation expressible as a sum over tensor products of states of R and L, and both L and R have thermal density matrix resulting in tracing with acceleration defining the Unruh temperature given by the trace of the second fundamental form for the curve (geodesic in question) [3]. At very small distances from wormhole throat QFT approximation works only for very high energies at the left hand side.

Final remark: I have suggested a p-adic version of Hawking-Bekenstein formula holding true at elementary particle level [2]. Maybe p-adic thermodynamics could replace blackhole thermodynamics in the case of elementary particles at least.

The conclusion is that blackhole and blackhole evaporation have TGD based generalization. The notion of blackhole like state would be very general and can be assigned with any physical system with a well-defined geometric shape (defined by the Euclidian space-time sheet). Gravitational blackholes would be only special cases. The notion of Hawking radiation identified as Unruh radiation could also make sense, and one could understand Rindler coordinates in terms of $M^2 \subset M^4$ decomposition central for quantum TGD. It is however essential that the acceleration parameter characterizing this radiation is defined by the trace of second fundamental form in the imbedding space: here GRT approach can be criticized of internal inconsistency. Since the interior of any TGD blackhole is Euclidian - this is absolutely essential- the argument leading to the firewall paradox fails. Horizon is in TGD framework a genuine firewall but this does not mean a failure of Equivalence Principle which only says only that Einstein's equations hold true for preferred extremals: Minkowskian QFT is always a good local approximation.

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