An Interpretation of QM based on the Holographic Principle and M-Cosmology

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Abstract. A quantum information interpretation of QM based on the Holographic Principle and related to the Horava Witten model of M-cosmology and the ensuing AdS/CFT duality will be proposed. This interpretation resumes the central idea of the relative state interpretation of H. Everett namely, that the wave function (of the universe) designates a fundamental reality. Yet it sharply differs from B. DeWitt's (Many Worlds) version of the original relative state interpretation and it has a different understanding of what makes up that fundamental reality. Bringing together features of the Holographic Principle and such of M-cosmology the basic assumption of the proposed quantum information interpretation is, that the observed universe should be seen as the 3+1 dim surface 'part' of a not observed 4+1 dim bulk 'part', where the wave function of the universe eventually relates to the *entire combined system*. The bulk space then can provide the (hitherto not located) 'storage dump' for the (informational equivalent of the) not observed quantum states. A further result of these considerations is, that the quantum theoretical feature of duality, which once had been introduced by Einstein in his work on the nature of 'Lichtquanten', is seen – yet closely together with the feature of yet again 'concealing' these dualities – as the very essence of QM.

The implicit connection of interpretative and cosmological aspects made by the quantum information interpretation then reinforces again what from their respectively very different angles already had been claimed by the relative state interpretation as well as D. Bohm's holistic interpretation of QM namely, that an appropriate interpretation of QM has a) in the perspective of the relative state interpretation directly to relate to the wave function of the universe or b) in the perspective of the holistic interpretation to the universe as a whole. These different perspectives are normally not seen as being directed to the same picture. Changing this perception is one purpose of this paper.

Motivations

The original motivation for this paper came from the belief, that the intricacies associated with the interpretation of QM have not to do with a lack of more or less exotic philosophical ideas[1], but with a severe lack of knowledge with respect to what quantum mechanics ultimately relates to, which is probably just another phrasing of the insight, that these intricacies have essential to do with the fact, that QM still seems to be 'eine unabgeschlossene Theorie'. The meaning of this insight probably has changed since it had been expressed for the first time. There is no more much doubt, that all the formalism and all technicalities of QM are pretty well understood, but it is rather the (making of the) fundamental physical reality it relates to, which simply seems to be still not fully unveiled.

As a consequence of that on the one hand the assumption of such a postulated fundamental reality has been questioned and on the other some substitutes for the still missing insight into that reality have been proposed. The former consequence led to all the different more or less subjectivist interpretations, which have their origin in the Copenhagen interpretation.[2] The latter then led to these non-subjectivist interpretations, which brought respective physical actions into play, which however unfortunately share the same drawback with the originally missing fundamental reality, namely to be undetectable.

Yet there is one objectivist interpretation, which took QM simply serious and this means first of all which took QM literal. As a consequence of that it – at least in its original formulation – hold back with any of such suitably postulated

[1] Quite on the contrary I tend to think, that some of the problems – though not the really puzzling ones – of the interpretation of QM had been first of all created by philosophical ideas. This relates especially to such 'problems', which – in this paper – I will refer to as 'quantum mystifications'. The perhaps most important reason to be against such interpretations that are based on philosophical assumptions is, that in my view a proper interpretation of QM will have to be falsifiable. Since it depends on specific cosmological assumptions the interpretation proposed in this paper matches this standard – perhaps too good.

I also must admit, that it is not without some irony, that this is a paper by someone with a philosophical background and – even worse – a paper containing almost no professional physical argumentation. But then the ideas put forward here are at least not derived from philosophical presumptions, but meant to be measured by their consistency with physical models.

[2] The – by its proponents always highlighted – fact, that the original Copenhagen interpretation stood all experimental tests is simply due to the fact, that the existence or presence of an observer, who him/herself is a decoherent object, *indicates* (i.e. is an index for) the observable universe the observer is a part of. Thus the seeming experimental corroboration of that interpretation is with respect to its significance equivalent to the significance of the weak anthropic principle, which is 'true' just in the sense that it is purely trivial. In the same sense the connection made by the proponents of the Copenhagen interpretation between the measurement process (and attached observer activities) and the behavior of quantum phenomena is trivial because measurement induces decoherence and quantum phenomena obey the quantum algebra. What the Copenhagen interpretation as well as any other subjectivist interpretation doesn't provide is even a hint of a proper *physical* explanation, why and how this observed behavior of quantum phenomena works as it works.

or fabricated hypostasized physical 'substitute realities'. That interpretation of QM is the relative state interpretation of QM, which had been originally introduced by Hugh Everett [1].
As the essential merit of this interpretation I regard the fact, that it directly and as focused as possible targeted the essential question of QM, namely to what fundamental reality, i.e. to what reality thoroughly transgressing the observable universe, it actually relates. And it did so under the premises, that this reality then was undoubtedly unknown in any of the details concerning its intrinsic build-up. Furthermore it had in admitting this even a central argument. By this the relative state interpretation left the question partly open, for which the time of complete answering had not yet been come, but was just for this reason apt to formulate the only precise and correct version of the very question itself. The answer it then gave was rather simple: 'The fundamental reality, to which QM relates to, is the implied ontology of the wave function (of the universe)'. I.e. the 'implied ontology' of the Schrödinger equation (of the universe) in the Born interpretation as a probability density function.[3]
That had several important consequences, one of which was, that the relative state interpretation overcame the dualism of the then still prevailing Copenhagen interpretation. And consequently it came to the result, that there are no classical objects, but only proper quantum objects. This result is of course equivalent to the solution, which the relative state interpretation provides for the so-called cut problem namely, that there is no cut, let alone a problem. The statement of the relative state interpretation, that there are no classical objects, will be a leitmotiv in the following. Yet concerning the more specific ingredients and makings of the mentioned implied ontology of the wave function (of the universe) the original relative state interpretation then still had to remain quite silent or 'unabgeschlossen'.
This doesn't hold for the Many Worlds interpretation [2]. This interpretation has for almost all the time since shortly after the introduction of the relative state interpretation been seen as its proper final version. And indeed the Many Worlds interpretation is a perfectly consistent model of the relative state interpretation and it is beyond that also as explicit as possible concerning a presumably implied ontology of it. And that presumed ontology proposed by the Many

[3] The central statement of the Everett interpretation is, that the Born interpretation of the Schrödinger wave equation has to be taken *literally*, i.e. that it has to be taken as designating a fundamental reality excelling if not superseding the reality of the observable part of the universe. By this Everett tacitly indicated a difference in the meanings of 'real' on the one hand and 'empirical' (or 'observable') on the other. Yet this not less radical than plain assertion also evoked the question of how the physical composition of this fundamental reality would stand. The hitherto prevailing answer to this question is known as 'Many Worlds interpretation', which is rather a further interpretation of Everett's relative state interpretation this time due to Bryce DeWitt.

Worlds interpretation is for many minds (including that of the author of this paper) regarded as being – quite literally – unbearable.
J. A. Wheeler once referred to that ontology as “too much metaphysical baggage”, by that refusing the consequence, that the Many Worlds interpretation requires and reserves for every decoherent or otherwise observed state a well as every seemingly nonlocal action an entire (copy of the) universe of its own. Wheeler’s cut was obviously to the point, but however it was not an argument against the theoretical consistency of the Many Worlds interpretation and it was of course also not meant to be that.
To overcome this excessive generosity but sticking to the very merits of the relative state interpretation, which is taking QM literally and that is taking the wave function as designating the – yet still unknown – fundamental reality (QM relates to), then motivates to look for a *parsimonious relative state interpretation*. Such a parsimonious relative state interpretation can’t by any means be without severe intricacies, since after all there was a very good reason for taking the Many Worlds interpretation as the proper version of Everett’s original proposal, namely avoiding nonlocal actions (with respect to the problems of interpretation brought forth by the EPR thought experiment).

Intricacies of a parsimonious relative state interpretation

The relative state interpretation says, that all quantum states of a respective quantum object are equally real, but that an observer normally, i.e. if looking at decoherent objects, only will see one particular of these equivalent (i.e. equally entitled to be taken as *real*) ‘complementary’ states of the object. The fact, that at one time only one of these states can be actually observed then has nothing to do with any presence or activity of any observer, but with the fact, that at this time the unobserved state is *not here*, i.e. is somewhere else, i.e. somewhere, where it is not observable.
Such semantics of ‘not here’ or ‘somewhere else’ are in my view not idle subtleties, but they go directly to the core of the answer Everett once gave to the questions concerning the interpretation of QM. This basic answer of the relative state interpretation, i.e. the answer, which all further interpretations of this particular interpretation have to be consistent with, is – in the light of the semantics of ‘not here’ – the following: the fact, that the unobserved quantum state ‘isn’t here’ does not at all mean that ‘it isn’t there’ (in the sense, that it does not exist).[4]

[4] Since the semantics of ‘not here’ and ‘not there’ will play a certain role in the following, now then a short terminological annotation: I will in that particular context use ‘not here’ as somewhat synonymous to ‘not being located in the observable universe’ and ‘not there’ as somewhat synonymous to ‘not being existent (at all)’.

In one respect this marks the already mentioned difference to the so-called collapse picture of the Copenhagen interpretation and the various rephrasings of that by its numerous offspring. In this respect the fact, that 'isn't here' doesn't mean 'isn't there' just says, that the non observed quantum state has the same reality as the respective observed state, i.e. that there is not a problem of existence, but of location. The problem then however returns by the fact, that that location in question might be laid not just beyond almost imagination, but also even beyond almost everything.

The inequality of 'isn't here' and 'isn't there' also marks a difference to some realist interpretations, which could be understood as saying, that the unobserved quantum state 'isn't there' by this implying 'is strictly hidden' or 'can by no means be found' but still 'is here', i.e. – so to speak – it 'is somewhere around here, but unfortunately strictly undetectable'.

Such an ambivalence concerning the maybe a bit confusing questions of 'existence' and/or 'location' of the non observable quantum states could even still be found, when – introducing their decoherent histories proposal – M. Gell-Mann and J. Hartle said, that "the off-diagonal terms in the decoherence functional vanish, in other words, decoherence results" [3, p 443][5]. What then is exactly the meaning of 'vanish'? Since it hardly can mean just a technical canceling out, it can either mean ceasing or a rather drastic change of 'location'. And since in the decoherent histories approach of Gell-Mann and Hartle one no longer is provided with an excess of universes to get rid of the off-diagonal terms, it seems the 'off-diagonal terms' have to vanish to a non-observable location somewhere in the observable universe. And – in the case, that that it is, what they've meant – that would be a graphic example for an interpretation of QM, where 'isn't there' has to be read as 'is somewhere around here, but can unfortunately not be found'.

But if one would read 'vanish' as 'a drastic change of location' and then place this location just across the edge of the observable part of the universe, so to speak 'in its aura or halo', then the decoherent histories approach could be seen as a decisive step in the direction to overcome the reason, why the relative state interpretation intrinsically tended to become the Many Worlds interpretation instead of becoming parsimonious.

Thus let me point out, that I think, that an essential difference in the approach to an interpretation of QM between other so-called 'realist' or – as I would prefer to say – objectivist interpretations of QM and the quantum information interpretation that I will introduce in the second part of this paper shows already in the analysis of the situation in question. I.e. these realist interpretations tend to

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[5] That paper of M. Gell-Mann and J. Hartle has been a most important step in the direction of a parsimonious relative state interpretation, primarily for introducing the concept of decoherence in the context of this type of interpretation.

say, that the not observable quantum states – though in a sense they are ‘not there’ or are ‘vanished’ – yet still are somehow ‘here’, whereas the quantum information interpretation, which will be the version of a parsimonious relative state interpretation that I will propose, says, that the not observable quantum states are quite and thoroughly ‘there’, notwithstanding the fact, that they are – thoroughly again – ‘not here’.

Decoherence

One important reason, why the relative state interpretation intrinsically tended to become the Many Worlds interpretation instead of becoming parsimonious, was Everett’s assumption of the inseparability of the observer and the observed quantum state as cocooned elements of one branch of the wave function, i.e. the neglect of the fact, that actual observers are decoherent systems. This can hardly be a reproach to Everett, since doing otherwise would almost inevitably have been seen as a relapse to the Copenhagen dualism or at least the classical-quantum cut problem in general, what he was just out to overcome.
Yet – on the other hand – the inseparability of the observer and the observed quantum state was also a sort of quantum mystification, which Everett – to my understanding - unfortunately had been enticed to adopt as well by the then still predominant obsession with the observer to (quantum) object relation, which however is a rather self created problem in the Copenhagen & Successors camp, as by the proper universalistic scope of his own claim.
The first of these two reasons is now only of historical interest, the second however has to be taken seriously. If the wave function of a quantum object in question (or under possible observation) is primarily seen as just an element of the wave function of the universe then certainly it should also be in whatever way ‘correlated’ (to avoid to say: ‘entangled’) with that part of the wave function of the universe, which relates to its observer. Obviously this was one of the two features of Everett’s original proposal, which implied its natural propensity for becoming the Many Worlds interpretation. The other was the task to consistently deal with – or rather dispose of – nonlocality.
Yet to come to a parsimonious relative state interpretation one has to overcome this propensity. One of the means to do so – at least in the cases, where nonlocality is not primarily involved – is to take decoherence seriously.

Overcoming the observer inclusion

The decoherence functional, which had been discussed by Gell-Mann/Hartle and others [4] has serious implications for dealing with sufficiently large complex objects – formerly known as ‘classical objects’– in general and such complex ‘classical’ objects as for example observers in particular. Since it follows from the decoherence approach, that such complex 'classical' objects can very well be treated as quantum objects without having to accept some absurd consequences, which earlier heavily contributed to what I call quantum mystification. A particularly confusing one had been the assumption, that treating a complex 'classical' object appropriately as a quantum object would strictly relate to all its typically coarse grained, i.e. supervenient features too. In the original relative state interpretation that then led to the excess of copying – beginning with the allegedly entangled 'observer plus quantum object' branch of the wave function and ending with entire universes.

But now we fortunately know, that there are anyway no classical objects in that former mystified sense (of the original Copenhagen dualism), but only proper decoherent objects, having disposed their off-diagonals. With respect to the problem of the observer inclusion in the original relative state interpretation that leads to the solution, that not the observer as such has to be copied for the reason to be appropriately taken as a quantum object, but that rather the vast amount of off-diagonal terms, which are associated with the observer (as a quantum object) has to be disposed – somewhere else. And it also leads to the insight, that, wherever that 'somewhere else' may be located, the disposed off-diagonals at least won't decohere again 'over there' to make a copy of that original observer, since off-diagonals just don't decohere.

This then also shows, that it doesn't contradict the unrestricted validity or universality of QM, if the emergent complexity features of sufficiently large and complex decoherent objects are *as such* not accounted for as proper quantum states (yet this does not mean, that they are seen as being 'classical'), since these supervenient complexity features are – so to speak – utterly superficies from the quantum state perspective.[6] In a sense all this follows immediately just from the very nature of such sufficiently large and complex objects as being decoherent objects. I.e. decoherent objects can – as entire objects – never be found in a state of superposition. But this does *not* say, that not *any* of their respective sufficiently small and less complex parts could regularly be found in superposition. Just the off-diagonals then have kindly to vanish, when these parts join to build a sufficiently large and complex decoherent whole.

Taking decoherence strictly and properly into consideration then effectively solves the seeming problem of the observer inclusion. It does so, since it leads to the insight that observers (as well as any other sufficiently large and complex emergent objects) already and – so to speak – *a priori* are decoherent objects. I.e. they must not and cannot branch off by observing quantum states being actually in the process of decoherence. That's for the reason that the observers

[6] In somewhat traditionally sounding philosophical terms this could be expressed the following way: applying quantum features to the *supervenient characteristics* of sufficiently large complex objects is mistaking *essence*, i.e. the respective supervenient complexity features, for *existence*, i.e. – in a most radical reductionist perspective or description – the physical composition of these objects.

already are 'splitted', i.e. decohered, objects. The various 'copies' or rather *'ensembles of off-diagonal elements'* of these observers then must not be conceived as either being stored in universes of their own or as being here (somehow hidden in this particular observable universe). But they should instead be seen as being stored somewhere else and not necessarily stored in the same physical setting as the actual observer (in this particular observable universe) is characterized by or from which he or she is built up.

A snapshot of that cat

With that we are prepared to see how another notorious cause of quantum mystification[7] would look in the perspective of a parsimonious relative state interpretation. That is the thought-experiment once brought forward by Erwin Schrödinger known as Schrödinger's cat[8] [5]. But by taking the effects of decoherence into proper account nearly every quantum mystification, which once had been associated with this experiment will vanish – and this time to nowhere.
Observers, 'steel chambers' or isolation boxes, cats, 'small flasks of hydrocyanic acid' and Geiger counters, hammers or other mechanical devices are all proper decoherent objects and will never be found in superposition. Yet that of course doesn't hold for "radioactive substances".
But no matter if this thought-experiment will be performed by the decay of radioactive substances or rather the measurement of a polarization of elementary particles (as a trigger for possibly killing that cat) in any of such cases the only question that matters for the task of interpreting QM would be *where* the 'vanished' states of the respective elements or particles have gone to.
And by taking decoherence properly into account, i.e. by admitting, that the observers, steel chambers, cats etc. already *are* decoherent objects, which means they are proper quantum objects, which yet cannot be observed in a state of superposition, one inevitably comes to the result, that the psi-function of the entire system would not relate to a mix of dead and living cats "smeared out in equal parts" and that the psi-function would also not relate to perhaps compara-

[7] One has however to point out, that Schrödinger's cat became such a cause of quantum mystification directly against the intention, which drove Schrödinger to present this thought-experiment. His intention was to ridicule the overdrawn observer inclusion. Yet the later reception of his contribution tended predominantly in the opposite direction.
[8] Here the relevant passage of Schrödinger's paper: "A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The psi-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts."[5, p 157]

bly confused mental states of respective observers – at least it would not relate to a confusion caused by the unpredictability of the radioactive decay.
The mental state of an observer of the originally proposed thought-experiment of Schrödinger's cat is anyway not differently affected than if there would no such explicit quantum feature be involved in the attempted killing of that cat, but instead the possible smashing of the poison gas ampoule would be triggered by a so-called 'classical' random generator, provided, that the respective algorithms could not be (separately) calculated in the time the experiment would take. After all there is a lot of so-called 'classical' lack of knowledge in the world.
This isn't meant to say either, that there is no 'psi-function of the entire system' (in the sense Schrödinger referred to) or that there are any classical objects (in the sense of the original Copenhagen interpretation). Quite on the contrary I hold, that there is not only a psi-function of the entire system Schrödinger refers to, but also even a psi-function of the *really entire* system as it has pointed to by Everett. And I also hold – again in *some* accordance with Everett – that there are no proper classical objects at all, but – now branching off from Everett's route – that there are decoherent objects, which then simply *are no classical objects*, but rather quantum objects their vast amount of off-diagonal quantum states vanished out of the scope of observableness and –since that is not due to a lack of observational power – out of the observable part of the universe to *somewhere else*.

Decoherence and interpretation

Decoherence provides the essential 'mechanism' for the emergence and further evolution of sufficiently large structurally integrated complex objects in the observable universe and thus it properly accounts for all of what once the unclear (if not utterly mystified) concept of the so-called collapse ever could have reasonably stood for. And it fortunately does not stand for any of the unreasonably claimed powers of that collapse as for example to create so-called classical objects. Decoherence just explains, how and why certain features of quantum objects vanish – due to interaction with the environment – out of the scope of observableness in the observable part of the universe or in a more strict relative state interpretation view: out of the particular reality of the *observable* universe.
Yet then the decoherence 'mechanism' also seems in the eyes of some – and perhaps sometimes in the eyes of Gell-Mann and Hartle too – instrumental for the 'origin of the classical domain' [3, p 430]. Fortunately they then make clear: "There are no classical domains, only quasiclassical ones." [3, p 445]
I would like to stress, that a major significance of the concept of decoherence is actually due to the fact, that it allows us to finally get rid of that old Copenhagen dualism, i.e. to get finally rid of any notions of classical or quasiclassical

domains or objects. Therefore decoherence must clearly not be misunderstood as something like a technically advanced version of Heisenberg's 'objective collapse'. Decoherence leads simply to no collapse whatsoever.
To overcome the Copenhagen dualism had also been an essential motive of Everett for presenting his original relative state interpretation, namely to show, that *there are no classical objects*, but only quantum objects and that the only solution of the cut-problem is, that there is no cut at all. Yet the fact, that there are such objects – formerly known as 'classical' or 'quasiclassical' – which for example can never be observed in superposition then contributed to the ontological overkill in the final version of his proposal. This was for two reasons: a) he didn't take decoherence into consideration (though the basic idea was already introduced by Nevill Mott in 1929 [6]) and b) even if he would have taken decoherence into consideration, he would still have had the problem where to *store* the vanished off-diagonals (if not in universes of their own). But, even if b) might in the end stand for a far greater problem, the consequence of a) already helps a lot.
Since by *taking decoherence seriously*, we now can say, that the decoherence 'mechanism' is absolutely instrumental for the origin or rather the emergence and evolution of a domain or rather a world of sufficiently large structurally integrated complex objects. I.e. it turns out, that the decoherence mechanism is absolutely instrumental for a world of *decoherent objects*. The seeming triviality of this statement is misleading. Since we can gain important information from it, namely, that we actually got rid of the stubborn illusion of 'classical' or quasiclassical domains or objects. There is neither a conceptual nor an ontological reason left to adhere to this illusion, since decoherent objects stand perfectly for all of that, what once had been reserved to the domain of 'classical' objects, yet decoherent objects are proper quantum objects, just quantum objects, for which the question "Where to store the vanished off-diagonals (if not in universes of their own)?" is still unanswered.
This brings us of course back to the reason 'b)' just mentioned above and to the conclusion, that decoherence despite its major significance for an encompassing (just to avoid to say 'holistic') interpretation of QM (i.e. an interpretation without a cut) does not provide a major contribution to crack the hard nut any possibly successful interpretation of QM will be confronted with. The reason for that is, that decoherence just doesn't tell us anything about a more fundamental reality encompassing the reality of the observable universe.[9] It doesn't even give us the slightest hint, *if there is such a fundamental reality or not.* And – upholding

[9] And it is for the reason, that decoherence doesn't answer the questions a) where the vanished quantum states are left (notwithstanding the fact, that decoherence tells us, *how* they vanish) and b) to what fundamental reality QM relates, why decoherence, despite its enormous significance, does *not* provide an essential contribution to the very question of the interpretation of QM.

the suspicious question and the following postulate[10] of Einstein [7] as well as Everett's basic idea of addressing that postulate – the author of this paper holds, that just *this* is the very question that matters for the interpretation of QM.
Thus let us come to a first summary:
Decoherent objects are proper quantum objects. They differ from quantum objects, which can be observed in superposition, just by the fact that decoherent objects – by definition – cannot be observed in a coherent state. The *process of decoherence* however can be observed in appropriate cases.
Since decoherent objects are proper quantum objects, the question, which matters for the interpretation, then is: "Where are the not (or no more) observed quantum states?" In the frequent cases, where the decoherent objects are sufficiently large structurally integrated complex objects like rigid bodies, sufficiently large organisms or observers, there is a very large amount of not observable quantum states (or off-diagonal terms) associated with the respective object, and also in these cases the question is: "Where are these not observed quantum states left?"
In the framework of the intended parsimonious relative state interpretation then the question is *not*, if there is anywhere a copy (or even more than one) of such a sufficiently large structurally integrated complex object (with or without an universe attached).
Thus *provisionally* it seems, that the desired parsimonious version of the relative state interpretation then could perhaps go as follows: the non observable quantum states become stored outside of the observable universe, just across its edge, i.e. – so to speak – in a kind of halo or aura of the observable universe, instead of being stored in these exorbitant Many Worlds.

Yet still a splitting force: nonlocality

But even if the problem of the observer inclusion, which in the original relative state interpretation came up for the reason of not proper accounting for the fact, that observers are decoherent quantum objects, had been an obstacle on the way to a parsimonious relative state interpretation that had eventually been overcome, then there still looms another obstacle much harder to overcome. That is the problem of nonlocality that once had been brought into the – since then enduring – debate by Einstein, Podolsky and Rosen [7], best expressed in the original EPR thought experiment, which later had been realized in a veritable physical experiment [8] as well.
Frankly, one has to admit, that in this case the hitherto intended version of a parsimonious relative state interpretation does not work and cannot work. Since it

[10] That postulate was, that QM could only be considered complete, if it could be formulated as a realist and local theory.

doesn't help, that the respectively vanishing states of the objects entangled at arbitrary distance might be stored in whatever aura or halo. For it is simply not about these states of the entangled objects, but about the instantaneous 'action' seemingly taking place in the experiment, i.e. an action, which appears to be nonlocal. Such a nonlocal action, seemingly taking place in the observable universe, then is neither subject to decoherence nor to storage procedures.

Therefore only two equally unpleasant 'solutions' seem to be left, namely either to attach a nonlocal action (taking place in the observable universe) to the hitherto sketched version of a parsimonious relative state interpretation, which then anyway would be no more that parsimonious, or simply falling back to the Many Worlds interpretation, and it doesn't make things better, that the implied lavishness of the Many Worlds interpretation might this time even be motivated by another ideal of frugality, namely to avoid any such spooky interactions and additions to proper QM, which had been frequently associated with nonlocality.

The only thing that really could help out would be, if this nonlocal action would not be *here*, i.e. if whatever effects these nonlocal appearances would not be in the observable part of the universe.

And since for example pilot waves in whatever disguise are by definition 'hidden' or undetectable, it would perhaps seem rather prudent to come to the conclusion, that whatever effects that nonlocal appearance might just exactly be characterized by that what it so manifestly shows just by hiding, namely that it is undetectable simply because it isn't there, what however in this special case rather means to say: isn't here. And 'isn't here' then doesn't mean 'isn't there', but – again – it rather means 'is somewhere else, where it is not observable'.

Before we will start to have an even closer look at the semantics of 'not here' and their relevance for the announced quantum information interpretation of QM, which shall be chosen to redeem the expectations, which hitherto have been laid upon a parsimonious relative state interpretation, I shortly will address a conceptual aspect concerning the interpretation of QM.

The opposite of the subjectivist interpretations of QM stemming from Bohr's original Copenhagen and carried to such extremes as Wigner's friend is in my view not (as it almost always had been thought by most of the contributors to this debate) a 'realist' interpretation – at least not in any epistemological sense of 'realism', i.e. in a sense closely associated with either empiricism or naturalism – but a non subjectivist, i.e. an *objectivist* interpretation.

An objectivist interpretation then would in contrast to a realist interpretation – if in fact 'realism' here refers to a sort of (how hidden or concealed ever) intended physical entity or actuality – not necessarily ask for any intended ordinary physical entities or actions – as e.g. pilot waves or quantum potentials – at all to do the job of the dismissed nonlocal action. And of course an objectivist interpretation doesn't bother where that, whatever does this job, should be considered being located. Especially the proponents of an objectivist interpretation should not be ontological protectionists concerning the universe they happen to stay in. Quantum states may be traded free across such – at least for the power of theoretical imagination – contingent borders as the edge of an observable universe is one of.

The quantum information interpretation of QM

The semantics of 'not here': From a parsimonious relative state interpretation to the quantum information interpretation

Since "somewhere else" just means nothing else and nothing more than: "not here" (where "here" again means: "in this observable universe") it might be the case, that the 'vanished' i.e. the not observable quantum states are just 'outside' i.e. just outside of this observable universe or just across its edge. But "somewhere else" does *not* mean or imply, that these vanished quantum states 'at the outside' or 'just across the edge' of the observable universe would or should have to be associated with another world or universe.

Yet there is one more seeming tacit implication, which might be not much less misleading than the one, which claims to need entire universes to store minuscule quantum states. This one has to do with the understanding of 'what is outside' or 'what is the edge (of what)'.

For most of the time, when the relative state (or the Many Worlds) interpretation had been discussed, the undisputed self-evident understanding was, that the observed universe would be the obvious *inside state* and the "somewhere else" laid storage of the vanished quantum states – wherever or whatever this may be – would have to be considered to be *the outside* of this universe. With respect to this 'outside' of the universe the difference between a parsimonious relative state interpretation and the prodigal Many Worlds interpretation would only be, that in the relative state interpretation this 'outside' could be located just across the edge of this universe – so to speak – in a sort of quantum halo, whereas the Many Worlds interpretation won't do the job for (or with) less than other universes as storage bin. Yet both these versions of the Everett interpretation of QM would in a rather unquestioned way hold the *observable universe as being the inside, the kernel or the bulk in this relation.*

And that's the hitherto unquestioned premise, which will be rejected by the quantum information interpretation of QM based on the Holographic Principle and M-cosmology, which is proposed in this paper. In accordance with the Holographic Principle and a certain model of M-cosmology the observable universe will not be seen as the inside or bulk or the kernel in relation to the storage bin for vanished quantum states, but rather as the outside, the surface or just as being at the edge of *a bulk (or kernel) with one additional dimension*. And that five (or 4+1) dimensional inside or bulk is proposed to be the “somewhere else”, which had been the synonym for the “not here”, which had been the answer to the question: “Where are the vanished (i.e. not observed) quantum states?” That 4+1 dimensional bulk or kernel then is proposed to be the looked for storage bin of the vanished, not observed quantum states.

The quantum information interpretation of QM based on the Holographic Principle and M-cosmology

Edward Witten once suggested, that M-theory[11] “may entail an explanation of quantum mechanics” [9]. The quantum information interpretation, which now will – at least as best the capabilities of the author allow – be sketched then perhaps could be seen as an attempt to contribute a bit to the efforts to make this anticipation come true.

One of the – together with decoherence and the Holographic Principle – three essential cornerstones this attempt recklessly utilizes had been presented by Petr Horava and Edward Witten in the context of the compactification of higher dimensional superstring domains to respectively lower dimensional ones [10]. Based on their results then a cosmological model called the ‘Horava Witten model’ gained some prominence in *string cosmology* (and might just by that also have indicated the turning point, from which on one should perhaps better speak of *M-cosmology*) [11]. In M-cosmology the Horava Witten model then gave a major impulse to the development of the so-called AdS/CFT duality, where already aspects of the Horava Witten model became somewhat amalgamated with the features of the Holographic Principle [11a].

A major result of the Horava Witten approach was that the origin of our universe could be envisioned as a five dimensional bulk space-time coming as the result of a compactification of an eleven-dimensional supergravity and that the observable part of the universe, i.e. the part we are actually living in, then has to be conceived as the (faster than the original five dimensional bulk part) expanding four – i.e. 3+1 – dimensional surface part of that original five dimensional universe.

Such a M-cosmological model would imply a drastic change to all our previous understandings of cosmology. There would neither be anything remotely similar to a singularity (not even to the – in the Pre Big Bang scenario of Gabriele Veneziano and Maurizio Gasperini – again by means of superstring theory altered configuration of a ‘triviality’[12]) nor to the idea, that the observable

[11] Witten actually referred to “superstring theory after the second superstring revolution”. [9, p 137]

universe started – so to speak – by a kind of concentric expansion from a tiny spheroidal beginning.[12]
But in the M-cosmological model based on the Horava Witten theory the observable universe rather started at the edge or *as the surface* of a respectively small five dimensional structure, not with a Big Bang and not with inflation, since the compactification from eleven dimensional supergravity is just meant to care for all of that instead. [13]
Yet in this paper I'm for obvious reasons neither concerned with the cosmological impact and consequences of the Horava Witten model nor with its M-theoretical underpinnings. Here the M-cosmological aspects of that model are just taken as presuppositions and it is made use of them for the proposed quantum information interpretation of QM. That has the – perhaps rather dubious – advantage, that such a proposal based on a secondary utilization is definitely wide open to falsification.
With respect to the task of presenting an interpretation of QM that
a) shall be based on proper physical assumptions and
b) follow the central ideas of Everett's relative state interpretation, namely that the wave function of the universe relates to a fundamental reality and that there is no dualism or quantum – classical cut and then
c) shall still operate parsimoniously,
the Horava Witten model of M-cosmology then eventually provides the long awaited 4+1 dim storage space for the not observable quantum states.

In FIG.1 a lower dimensional analogy of the situation I refer to is shown.

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[12] It must hardly be stressed, that such a M-cosmological model would have a drastic change of our understanding of the observable universe (formerly known as 'the universe') as a consequence. The observable universe would then undergo a change of status from the be-all and end-all of a post-eleatic onto-centrism to something like a sort of peripheral 'ectoplasm' of the unobservable bulk (part of the entire combined universe).
[13] For a discussion of these implications of the Horava Witten model in the context of a critical assessment of the ekpyrotic model of P. Steinhardt, N. Turok et. al., which also got essential inspiration from the Horava Witten theory, cf. [13].

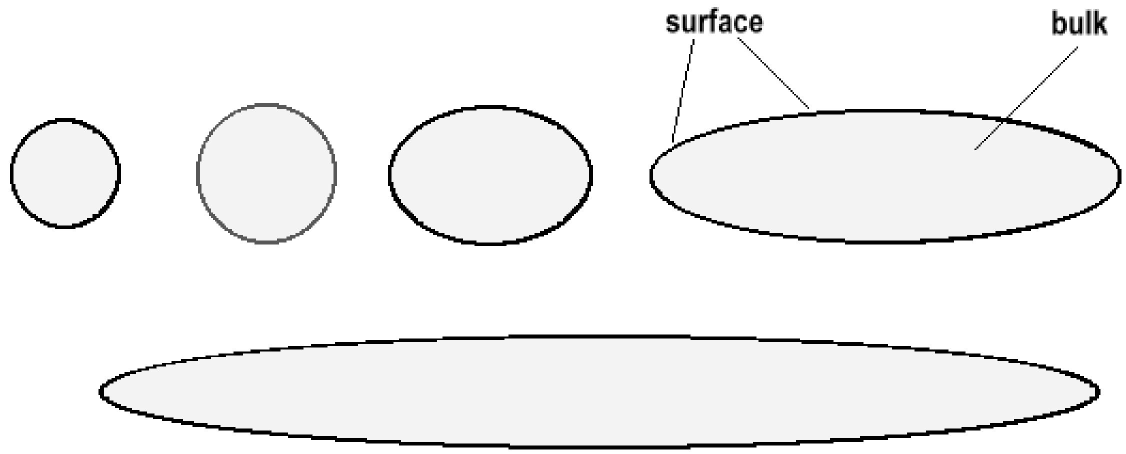


FIG.1

FIG.1 shows in the most simple diagrammatic manner the 'expansion of a two dimensional 'universe' with a one dimensional surface' (or equivalently some cuts through the respective stages of the expansion of a three dimensional universe with a two dimensional surface). What differs from other illustrations with a comparable 'object' in focus is, that this two dimensional 'universe' somehow seems to loose its proper shape or just seems to become a bit rambling at the third stage of its evolution. By that the original circular shape and concentric expansion will change to a rather – yet not necessarily regular – elliptic shape and in FIG.1 that is additionally correlated with a faster increase of the perimeter in relation to the volume. In the two later stages of that evolution shown in FIG.1 that faster increase of the perimeter compared to the volume goes on and that leads to an increasing *flattening* of the ellipsoid in question.

Now, in the two-dimensional case and also in the three dimensional case (with two dimensional surface) that might possibly be not of much interest for many people. But that could perhaps change in the case, where a comparable expansion is considered for a 4+1 dimensional bulk space with a 3+1 dimensional surface, especially when the latter becomes somehow associated with the observable universe. The different expansion rates of the 3+1 surface and the 4+1 bulk part of the universe as shown in FIG.1 could also be the result of other conditions as those supposed in FIG.1. They would also follow from a scenario, in which the bulk part is assumed to come to an end of its expansion and/or in which it maintains a constant volume[14], or perhaps even another one, in which it

[14] The five dim bulk part could in such alternative scenarios either also keep its original size or volume from its beginning as a result of compactification or keep a particular volume reached at any later

would – slowly – decrease from an original size, i.e. volume. Yet it would in all cases be required, that the surficial part (i.e. the equivalent to the observable universe in such a model) would have to increase and, if both parts increase, then to *increase significantly faster* than the bulk part.[15]

If such a cosmological model, somewhat 'associated' with M-theory, could possibly stand the test of cosmological evidence, it then would also immediately suggest itself to become explored with respect to the applicability of the Holographic Principle.
The Holographic Principle[16] had been introduced by Gerard t'Hooft [15] and Leonard Susskind [16] in the context of black hole thermodynamics. L. Susskind then also discussed the Holographic Principle with respect to its significance in superstring theory, where it soon turned out to be a generic feature of that theory [16]. It soon also became intensively discussed in the particular context of superstring- and M-cosmology [17]. And it is in this context, where it possibly connects to the quantum information interpretation.

In its original formulation by t'Hooft and Susskind the Holographic Principle said, that the information content of an appropriate spatial region, e.g. a black hole, can be fully described by the information content of the area of its surface (with one bit of information per one unit of the Planck size of the surface). That original Holographic Principle then could possibly be generalized to state, that the information content of any appropriate *n* dimensional stable spatial region can be found represented in its *n-1* dimensional boundary.
If the Holographic Principle could possibly be applied to a cosmological model in line with the toy model shown in FIG.1, then this would imply, that the observable 3+1 dimensional part of the universe is something like a display of the information content of the 4+1 dimensional part of the universe, of which it is the boundary. And this relation would of course also hold vice versa. The basic assumption of the quantum information interpretation then is, that the puzzling features of QM – so to speak: the 'quantum phenomenology' – are due to the significantly different ways this *equivalent information* is stored at the surface part on the one hand and in the bulk on the other and by that, that these features

stage of a possible (and highly probable) expansion. The quantum information interpretation of QM proposed in this paper would be consistent with any of such M-cosmological scenarios.
[15] Even though in this paper quantum information states are just the stuff we are interested in, that must not preclude, that such a five dim bulk part of the universe might also be useful to store other things, which share the feature of stubbornly denying to be observed with the ‚vanished' quantum states. Since after all the capacity of that five dim bulk might well be apt to store enough dark energy and dark matter to also serve as the *heart of darkness* of the entire, i.e. combined universe.
[16] For a comprehensive review of the Holographic Principle cf. [14].

are not less due to the *filtering*, which takes place in the mapping of this information from the surface to the bulk and vice versa.
One important difference may very well be, that the bulk way of storing information is more 'effective' in a sense. I.e. that in the assumed 4+1 dimensional bulk part all 'complementary' or rather *dual* quantum information states are actually copresent, whereas in the 3+1 dimensional surface part in many cases only one of such complementary states can be observed at one particular time. That is not to say, that the information content on the surface would be less than that in the bulk, since the observation of one of two 'complementary' states entails the information about the not observed one as well. There would then be no difference in the information relating to the *reality* of the not observed quantum state, but just a difference with respect to its *actuality*, i.e. the question of how that reality is actually expressed or – in a less favoured way of describing this – if this state is actually observed or not. And 'information' telling us, that an observed state is observed and a not observed state is not observed is not particularly telling us much at all.
The aspect of different efficiency in storing the equivalent information content with respect to either the surface or the bulk part of the universe seems in my view to further support the assumed link between the proposed M-cosmological model hinted at in FIG.1 and the Holographic Principle. The increasing variable in the surface part of the universe as well as in the bulk part appears to be their respective entropy, i.e. the thermodynamical history of the surface (i.e. the observable universe) on the one side and its informational equivalent in the bulk on the other. That the five dimensional bulk part of the encompassing entire universe is a far more effective storage for the quantum informational equivalent of the thermodynamical entropy of its surficial part is then quite in line with the assumed (and now also required) faster increase of the expansion of the surface part of the universe compared to its bulk part.
If the applicability of the Holographic Principle to a cosmological model consisting of a five dimensional bulk part and a four dimensional surface part of the – both parts equally encompassing – entire universe, where the surface part would correspond to the observable universe, could be possibly corroborated, then the observable universe itself should be seen as something similar to a 'hologram', quite in line with the paraphrase of "The World as a Hologram" once used by L. Susskind.
Concerning this metaphor of a 'hologram' I however think, that the situation of an observer in the 3+1 dim universe observing quantum phenomena is even more different from the situation of an observer looking at an ordinary hologram than it obviously appears. The main difference comes of course from the fact, that the observer in the 3+1 dim universe is him/herself just a part of that 'hologram' he or she is assumed to look at as well. Taking this unavoidable participancy into account it seems, that the Holographic Principle rather invites us to

see the 3+1 dim observable universe as a kind of complicated ‘interface’ of the 4+1 dim bulk part of the universe on the one side and the decoherent observer as a proper part of the 3+1 dim surface part of the universe on the other.
Therefore it then requires in the *quantum information universe* case much more abstraction than in the case of an ordinary hologram to account for that unavoidable involvement of the observer or maybe better: to cancel it out.[17] Since for the participant observer the observable universe appears less to be a hologram than rather to be a kind of semitransparent mirror, at which it seems hard to distinguish between, what it shows, from, what’s behind, and, what it reflects, from, what is and what *happens* in front of it.

Quantum through the looking glass[18]: concealed duality

Thus now we will try to take a look at what’s behind that mirror the eyes or rather the mind aided with trust in the proposed M-cosmological model as well as with hope, that that mirror behaves according to the Holographic Principle. In particular we want to see, if the problem of nonlocality as exposed in the EPR experiment and still unresolved even by taking decoherence into account may find a better explanation.
The quantum information interpretation based on the proposed M-cosmological model and the Holographic Principle just claims, that the entire quantum information state relating to the two arbitrarily distant yet entangled particles like e.g. electrons with respectively two dual (also known as ‘complementary’) quantum states like spin up and spin down is *actually copresent* in the 4+1 dimensional bulk part of the universe and – in accordance with the Holographic Principle – mapped (or projected) at (or to) the 3+1 dimensional surface part of the universe. Yet obviously here it doesn’t show its proper actual copresence, when being manipulated with or sufficiently sharp looked at. In such an experimental situation the looked at one shows only one of its two dual states and an alleged nonlocal action is assumed to take place seemingly instantaneously transmitting the necessary information to the other sufficiently distant one to make this one showing the respectively dual state.
And that already implies the quantum information interpretation of the EPR situation. The quantum information interpretation reduces the seeming nonlocality in the surface part of the universe to the concealing of an underlying dual-

[17] The relative state interpretation of H. Everett was in my view the first one, which dared to face the challenge of the ‘required abstraction’, whereas the many subjectivist interpretations of QM took that unavoidable involvement or participancy of the observer to shield their anthropocentric resentment, which historically often was closely associated with a resentment at mustering the respectively ‘required abstraction’.
[18] That phrase might perhaps induce some to see the quantum information interpretation as a sort of ‘quantum in wonderland’.

ity of dual quantum information states. This unconcealed duality is yet still unreduced copresent in the corresponding five dimensional bulk part of the universe.

That concealment of one of the dual states of the ‘entangled at distance’ quantum system in the EPR situation is caused by the – in the surface part of the universe *local* – action reducing the dual quantum state of the particular particle (by manipulating e.g. polarizing) to one of the original two pictures. By this – so to speak – ‘surficially’ local action the dual state of the whole entangled system becomes instantaneously accordingly reduced.

This follows a dictum of Erwin Schrödinger, who already has said a long time ago, that quantum objects once entangled remain entangled not regarding how far remote these objects become later. That statement was directed as well against any miraculous observer power as against the assumption of any nonlocal action carried by hidden forces in the observable universe.

The ‘mechanism’ the quantum information interpretation proposes to be responsible for that nonlocal appearance or effect (in the surface part of the universe) of the seeming transmission of the reduced quantum state of the particle ‘at hand’ to the whole entangled at distance quantum system is no mechanism at all, but rather a direct consequence of the Holographic Principle. Since the Holographic Principle states, that the entire information of the quantum states of a respective bulk space is mapped on (or projected at or represented in) a respective surface, it also directly follows, that any change of the informational status of the quantum states at the surface is itself again mapped to the bulk space. That happens, if in the EPR situation the quantum state of the particle ‘at hand’ becomes reduced by a surficially *local action*.

Yet since the Holographic Principle unweariedly states, that the entire information of the quantum states of the bulk part of the universe is mapped to (etc.) the respective surface part, the then respectively altered bulk information – now including the additional information about the change of the informational status of the quantum states at the surface caused by that surficial local action – becomes also instantaneously mapped again ‘back’ to the surface. And since the entangled system is an entangled system this ‘mapped back again’ information relates to that entangled system as a whole. And that’s the quantum information interpretation of the nonlocal appearance in the EPR situation caused by one local action in the surface part of the universe and actualized in that surface part by two instantaneous mappings – forth and back.

The result of that playing the information with rebound is, that – caused by the surficially local action – one of the dual states of the whole entangled quantum system has vanished or rather is concealed in the observable 3+1 dimensional part of the universe.

Then the question comes up what ‘happens’ in the bulk space, when the information about the reduction of the dual quantum state of the particle manipulated

by that surficially local action is processed in the bulk. That is in my understanding the question, if there takes another action place in the bulk part of the universe or not. In the case that this question would have to be answered positively then a next question would come up, namely the question, if such an action in the bulk part of the universe would be a nonlocal action or not.
In the attempt to find answers to these questions we will try to support our imagination by having a look at the following FIG.2.

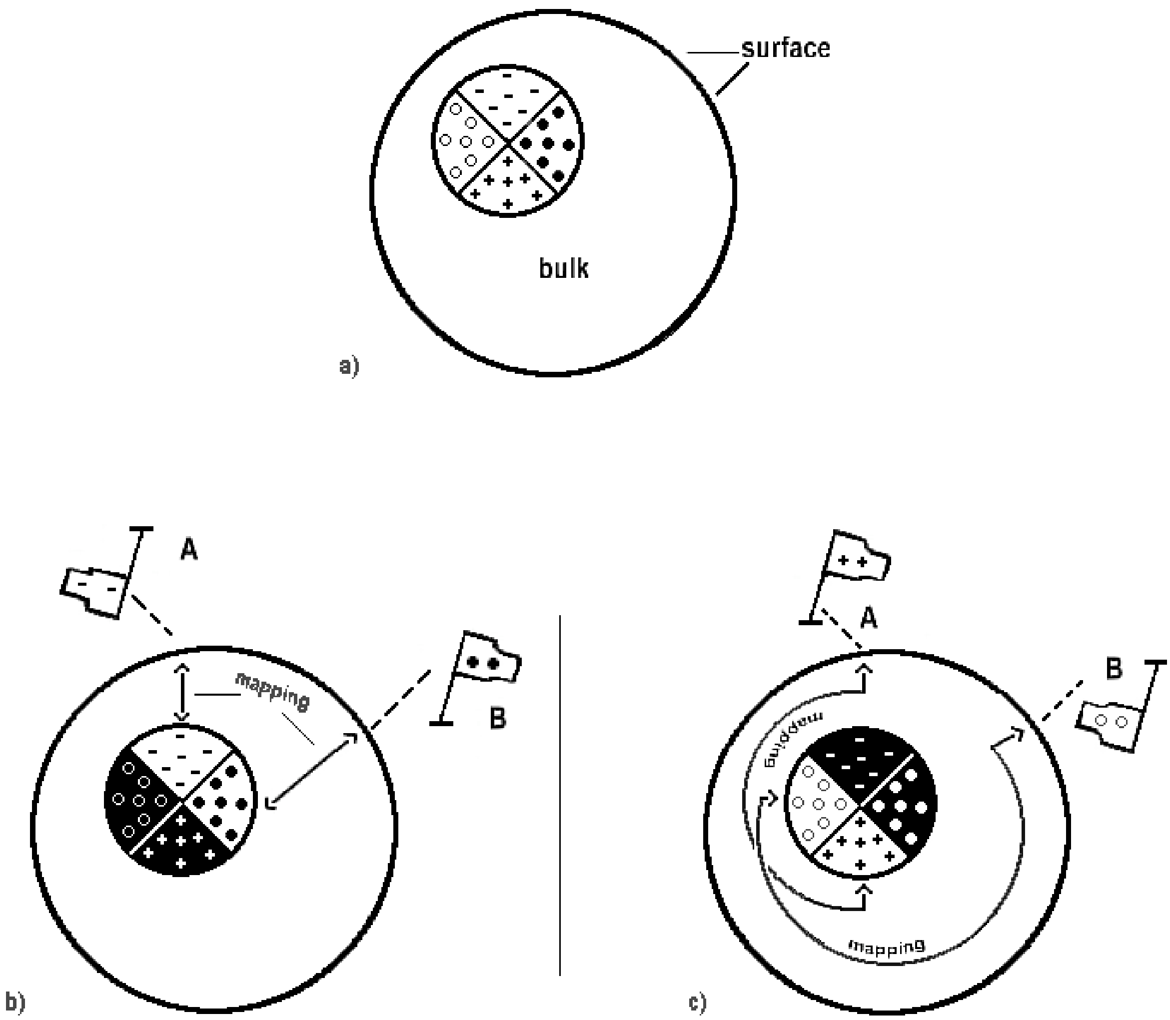


FIG.2

FIG.2a shows the nonreduced or nonobserved coherent quantum information state(s) of a pair of entangled particles, which have to be supposed or imagined at the surface, but are of course not shown or visible, since after all they are supposed not to be observed. The respective dual quantum information state(s) of one of the two particles is laid in (the angular domains of) one of the two corresponding angles shown in the inner circle in the bulk, and accordingly so for the other. I.e. '+' and '–' symbolize the dual quantum state of one of the two assumed particles and accordingly '●' and '○' symbolize the dual quantum state of the other assumed particle. What FIG.2a implies is, that the entire quantum information state in the bulk, which is correlated to the whole entangled system (assumed to be) on the surface, is simultaneously copresent and – so to speak – activated at least as long as the correlated entangled system on the surface is not reduced.

What according to the quantum information interpretation should happen, if the entangled particles in the surface undergo an EPR treatment, then is shown in FIGS.2b and 2c. In FIG.2b one can see an object (or particle) A, which shall be the double of the particle 'at hand', i.e. manipulated by a local action, in an EPR situation, showing a (quantum) state 'flagged down', which is characterized by '–'. From this follows as well, that the respective dual quantum state of particle A (characterized by '+') cannot be observed, i.e. is vanished or concealed, as also, that the entangled particle B shows the 'complementary' (to the one observable at particle A) of *its* respective dual quantum states, namely the state 'flagged up' (characterized by '●'), whereas the respective dual quantum state of particle B, namely 'flagged down' (characterized by '○') then of course can also not be observed, i.e. is vanished or concealed.

Accordingly in FIG.2c the particle A then presents – probably after a further manipulation – the previously concealed state 'flagged up' (characterized by '+') and has its state 'flagged down' (characterized by '–') concealed. Then the entangled particle B now shows – again accordingly – its quantum state 'flagged down' (characterized by '○') and has *its* respective dual quantum state, namely 'flagged up' (characterized by '●'), concealed.

In the bulk the entire information about what happens in that EPR situation could possibly be stored or represented – and then *instantaneously mapped back to the surface* – in the way shown in FIGS.2b and 2c[19], namely by marking the quantum information states equivalent to the not observable, vanished or concealed states at the surface (alternatively also the quantum information states equivalent to the observable or not concealed states at the surface could be marked and the dual ones then left unmarked). In FIGS.2b and 2c that marking comes in the form of inverting the symbols (and the background) in the respective angle domains. In FIG.2b that are the *inverted graphic representations* of '+' and of '○' and in FIG.2c the *inverted graphs* of '–' and '●'.

What happened then in the inner circles of quantum information representation in the bulk? Was there a local or nonlocal action involved? It *seems* at least, as if there happened three things.

[19] In fact that information can be stored much more effectively as will soon be shown below.

In FIG.2b the 'process' started with the quantum information state characterized by '–' getting the information *mapped* from the surface, that its equivalent state at the surface namely 'flagged down' of particle A became actualized or observed. Therefore at first its dual bulk state '+' had to be marked or inverted and secondly its neighbour in clockwise direction '●' had to be informed to be activated or in charge for mapping its quantum information state back to particle B, which then would show the surface state 'flagged up', and then thirdly the dual bulk state of '●', namely '○', had also to be marked or inverted.[20]
Accordingly in FIG.2c the surface state 'flagged up' of particle A became mapped to the quantum information state characterized by '+', then the dual state '–' of this state had to be inverted and then its neighbour in clockwise direction '○' had to be informed to be activated for mapping its quantum information state back to particle B, which then would show the surface state 'flagged down', and then the dual bulk state of '○', namely '●', had again to be marked or inverted.
Obviously the mapping of the information from the surface forth to the bulk and back again are no actions at all. But what's about the marking or inverting and what's about the transmission of the information to the neighbour in clockwise direction (in the bulk), that it is now in charge a) to mark (invert) its dual twin and b) to map its quantum information state to particle B at the surface. It is not so obvious, that these three happenings in the bulk are actions at all and it is even less obvious, that, if there would be an action involved, such action would have to be a nonlocal action.
Yet one thing at least is obvious, namely that the FIGS.2a, 2b and 2c contain much too much redundant information due to a too much surficial – or observer infected – view of the bulk state, which after all is as such first of all a space of – from an observer's point of view – utterly concealed states. And due to this there also may even to many seeming actions – nonlocal or other – be contained in these figures.

Concealing the quantum information duality by highlighting the equivalent to the observable state

When we look again in FIGS.3a, 3b and 3c at the same EPR situation in the quantum information interpretation environment as above, but now not from the surficial observer point of view (or with this view overly in mind), then we will see a certain slimming down of the number of symbols symbolizing the four particular states of the two dual quantum information states in the bulk. I.e. we will only see two symbols, namely '●' and its marked (or inverted) image. And

[20] That kind of enumeration must not and shall not imply a time sequence of whatever actions or else.

even these two symbols are again actually redundant and only kept for reasons of (a more contrasting) illustration and easier description.

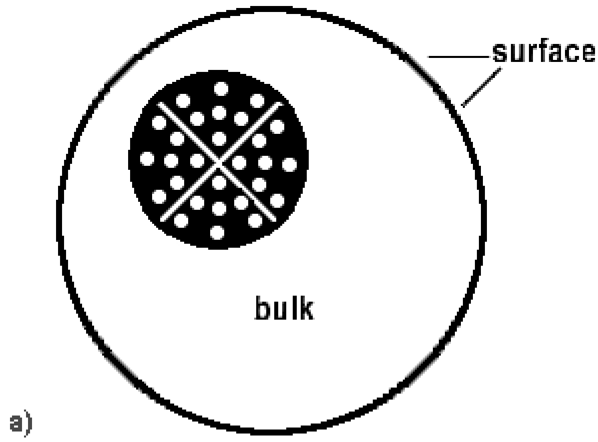
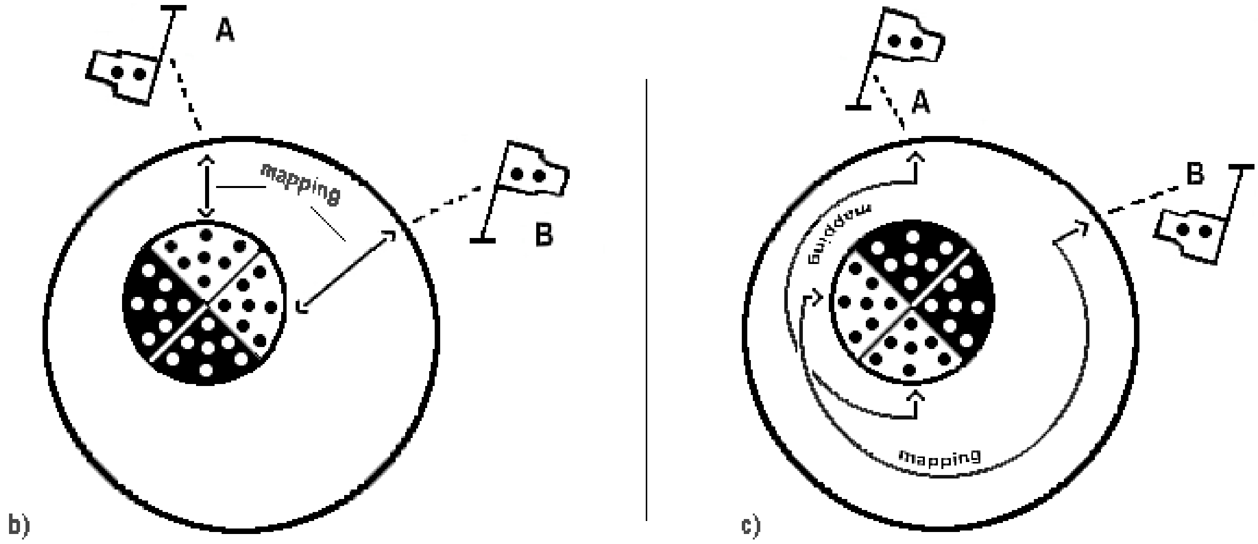


FIG.3a

In FIG.3a all four angle domains of the two corresponding angles, which stand for the two dual quantum information states in the bulk, which are equivalent to the two dual quantum states of the not observed whole entangled system on the surface, i.e. the two dual states that system is actually in, when it is not observed, show even only one symbol, namely that marked (or inverted) image of '●'.
That is – in difference to the representation chosen in FIG.2a – the appropriate representation of the quantum information states in the bulk, since FIG.3a is meant to represent these quantum information states as equivalent to the *non-observed* quantum states on the surface. I.e. quantum information states in the bulk equivalent to non observed quantum states on the surface have to be shown as – in the terminology introduced in the preceding paragraph – *concealed* quantum information states, since the concealed (or marked or inverted) quantum information states are already in FIGS.2b and 2c consistently treated as being the bulk equivalent of the not observed quantum states at the surface. The mistake in FIG.2a just was to start with two dual *not* concealed etc. quantum information states in the bulk, which would rather be the equivalent of the whole entangled quantum system in the EPR situation *manipulated and still observed in superposition.*
Thus in FIG.3a we will do better and start with the proper equivalent to the quantum state(s) of the whole entangled system on the surface, when it is neither manipulated nor observed, i.e. with the respective quantum information state(s) concealed or – graphically – inverted.

And by starting properly then the number of actions involved in the EPR situation decreases to its possible minimum.



FIGS.3b and 3c

In FIG.3b we can see, that – caused by the surficial local action, which is the only relevant action the entire EPR experiment consists of – the surficial quantum state ‘flagged down’ of particle A becomes *actualized* and that information becomes mapped to the bulk, where by that the respective quantum information state becomes *highlighted* or activated. Then the neighbour in clockwise direction in the bulk becomes highlighted or activated and the information about that becomes mapped to particle B at the surface, which then shows quantum state ‘flagged up’. In FIG.3c, where it is supposed, that choosing quantum state ‘flagged up’ of A starts the experiment, everything happens accordingly.
In this scenario only one proper action occurs in the bulk. That is the transmission of the information, that it now has to become activated, to the so-called ‘neighbour in clockwise direction’, i.e. the bulk quantum information state equivalent to – in FIG.3b – the surficial quantum state ‘flagged up’ of particle B.
Some of the work the hypostasized ‘nonlocal action’ (on the surface) had been designated for then is done by the mappings forth (to the bulk) and back (to the surface) in line with the Holographic Principle. *And these mappings are no actions at all.*
But the really hard job is done by that action of activating the quantum information state in the bulk equivalent to the observable quantum state of particle B. It is that action, which effects the appearance of nonlocality at the surface, i.e. to the surficial observer perspective. And there is – at least for me – no obvious

reason, why that action in the bulk should not be a perfectly local action (in the bulk).
The notions of 'locality' and perhaps also 'nonlocality' will anyway undergo a certain change in meaning, if applied to a five dimensional quantum information storage. Yet, since the bulk is – at least in the perspective of its utilization in the quantum information interpretation of QM – first of all a five dimensional quantum information storage, that could even further strengthen the anti nonlocality cause. At first a 4 (+1) dim space(time) provides much more opportunity for close contact or immediate neighbourhood than a 3 (+1) dimensional one. And, secondly, storing of information about arbitrarily distant states does not require in any sense *distant storing*. What it probably would require, would rather be information about that particular distance. And in this case that information can again be stored in the immediate neighbourhood of the other relevant quantum information states in question.
Thus it seems, that there is – quite literally – no space left for nonlocality, since immediate neighbourhood is not just an allowed but almost a required feature of effective quantum information storing in the bulk part of the universe.

The fixative for quantum information: dodging dualities

Since it becomes more and more obvious, that the feature of duality as well as the ways of in one instance concealing the dual states or in another dimming them seems to be central for the quantum information interpretation, we will now turn even more directly than we already did to the original or paradigmatic duality, namely the wave – particle duality of quantum entities. At first we will shortly consider the question, if there would quantum information states in the bulk related to the double slit experiment, in which the wave – particle duality indirectly, yet nevertheless clearly, is shown, have to be expected. I think the answer has to be 'yes'. But the quantum information states equivalent to the surficial situation of the double slit experiment performed would then be not so directly related to the nature or features of the particles, i.e. photons, involved as for example in the EPR situation. That is so for the already mentioned reason, that the double slit experiment only indirectly relates to the dual nature of the photons.
In the case, when only one slit is opened, one can find a pattern of traces or imprints on the detector screen, which are perfectly in line with the assumption that photons are proper particles. But that accordance comes entirely from that *pattern*, which definitely shows no indication of the wave nature of photons. On the other hand any *individual trace* on that detector could of course equally be caused by a hit of a tiny wave as by a hit of a tiny particle just because there would be no difference then in the appearance of the individual trace at all.

In the case, when both slits are opened, the experiment becomes interesting. Now one can find a pattern of traces or imprints on the detector screen, which indirectly prove the assumption, that photons have a wave nature as well. Again that accordance comes entirely from that pattern, which now needs a bit more explanation than in the 'one slit open' case is required. That explanation says, that the photons of both – by passing through the slits aligned – lightbeams interfere. And that interference then causes the pattern (on the detector), which indirectly shows the wave nature of the photons involved. Yet again any individual trace caused by an individual hit could equally be caused by a particle or a wave for the same reason as above.
As a consequence of that the quantum information state equivalent in the bulk would hardly look related to any surficial experiment. In the 'one slit open' situation it would – related to the wave-particle duality – show nothing particularly different from that, what it would normally show, namely that both natures exist with equal rights. In the 'two slit open' situation it would show the same, but there would probably also information be stored about occurring interferences, since these would influence surficial quantum states. Yet that these interferences occur in the surficial context of an experiment related to the duality of the wave and the particle nature of photons, would rather be unnoticed in the bulk.

That the wave particle duality is only indirectly shown by the double slit experiment, does however not diminish at all the central role and the eminent significance that the feature of duality has in and for the quantum information interpretation.
In the light of the quantum information interpretation the feature of duality is rather the essential feature of QM. It dates back to its original discovery by Einstein as the duality feature of Lichtquanten as discrete entities as well as waves in (one of) his famous paper of 1905 [18]. This duality then had been further explored by Einstein in two papers of 1909 [19a, 19b]. Einstein didn't then fully see this duality as one of proper particles and waves, but he preferred to speak of Lichtquanten as "voneinander unabhängig beweglichen, punktförmigen Quanten" [19a], a view which comes very near to the later emerging concept of a photon. By introducing the *momentum* of Lichtquanten [20] he then – albeit somewhat reluctantly – clearly exposed the *particle nature* (as one of the two dual natures) of the Lichtquant.
In direct continuation of that work of Einstein L. de Broglie then extended that original duality of Lichtquanten to (other) particles and stated it explicitly as the duality of corpuscles and waves [21]. Since then the wave particle duality has been the paradigmatic duality in QM.

In the quantum information interpretation the feature of duality showed its importance in the interpretation of the EPR situation, where it occurred as the concealing of either one or the other of two 'sides' of a dual state or – when looking at the entire entangled system – of two combined dual states.
Yet the feature of duality or rather the feature of its concealing or suppressing also plays an important role in the apparently quite different case of decoherence. That is for the reason, that decoherence doesn't lead to a world of classical or semi-classical (whatever that shall be) objects, as I already stressed above in the respective paragraphs. The decoherent objects are rather proper quantum objects, but just such quantum objects, of which a vast amount of quantum states is not observable. And many if not all of these not observable quantum states are just belonging to these sides of dual quantum states, of which the other sides are actualized in the deeply entangled and intensively interacting ensemble of quantum entities, of which the decoherent object eventually consists of and is made up. I.e. the decoherent object must be seen as the result of a vast amount of intensively interacting quantum entities, where however this interaction itself at first induces the 'vanishing' or concealing of the superposed or dual states of the quantum entities involved.

Yet, in my view, the centrality of the feature of duality in the quantum information interpretation also indicates something more far reaching. It indicates the fundamental incompleteness of the observable reality. And by that it already unobtrusively transcends the reality of the observable universe, quite in the spirit of Everett's relative state interpretation. But for Everett the quantum cosmological domain his interpretation related to was then utterly uncharted territory, whereas for the quantum information interpretation it is just an – assumed – presupposition.
The Horava Witten model of M-cosmology not only provides the five dim bulk part of the universe for storing the quantum information states as equivalents of the vanished quantum states (of the observable universe), but it also links the traces of dualities, which almost in obscurity reach down to the particularity (also known as 'reality') of the observable universe, to the domain of their veritable presence. At least the six outposts of this domain are meanwhile charted and occupied by various superstring theories and 11-dim supergravitation. Yet since it had been said, that unknown monsters might hide in the middle of that domain, I will not take further risks and let it rest there.
Yet such as the breaking of symmetries is an accepted way of understanding the precipitation of the low energy domain of the so-called semi-classical world also the concealing (or suppressing or dimming) or – in general – the filtering of the 'complementary' states of dualities should not only be seen as an even more fundamental principle than that of symmetry(breaking), such as it is– to my understanding – done in M-theory, but also as an not less important element of

the very nature of the fundamental reality of the particular universe, to which any objectivist or ontological interpretation of QM tends to relate to.

And by that transcending of the physics of the observable universe the feature of duality also reinforces the underlying philosophical motivation of the objectivist and ontological interpretation of QM, as which the quantum information interpretation has to be seen. Namely overcoming the – more or less tacit – anthropocentrism of the Copenhagen and other subjectivist interpretations, which have been a last bastion of a somehow pre-Copernican observer-centric resentment. That observer-centrism then always preferred to take the projections of its epistemological presumptions or the scope of its operationalist reach as the ultimate limit of conceivability than instead consider the reality transcending the narrow limitations of these projections and that scope.
But by pursuing the aim of overcoming that observer-centrism we have been – again quite in the spirit of the relative state interpretation, yet in the end even going much further – carried away and got the presentiment, that not only the observable (part of the) universe, but even the *entire universe* (as proposed in that paper) is neither the totality nor the paragon of fundamental physical existence, but just a particular instance in the – in this respect somewhat Meta-cosmological – M-cosmology.

'Interpreting' the quantum information interpretation

And such ideas lead us to the somewhat self-referential twist of trying to 'interpret' the quantum information interpretation. The original motivation, by which we became instigated to all of that, what followed, was to look for a parsimonious relative state interpretation of QM. And therefore we will at first have a look, if the quantum information interpretation qualifies for that.
The problem of Everett's relative state interpretation was, that it had a natural inclination to become the Many World interpretation, if and when it became scrutinized with respect to its implied ontology. And the task of a parsimonious version of the relative state interpretation then had to be to provide an alternative to the unbearable prodigality of the Many Worlds interpretation.
For the quantum information interpretation being fit for that task three things had been required: a) a storage for the seemingly 'vanished' or not observable quantum states, b) a new understanding of the nature of quantum states regardless, if they are observed or not observed and c) an appropriate link between the world, in which – some – quantum states are sometimes observed, and the domain, in which the not observed ones then are properly stored.
The storage then was found by (ab)using the five dim bulk space of the Horava Witten model of M-cosmology for that purpose. And the link was provided by the Holographic Principle. And that had consequences for the understanding of

the nature of the quantum states involved. At least the not observable bulk stored quantum states formerly known as 'vanished' had to be reinterpreted as *quantum information states*[21], and that is again warranted as an implied consequence of the Holographic Principle. In a more philosophical or rather 'ontological' perspective this reinterpretation could, in my view, have the most far-reaching consequences. And it will soon turn out to mark the decisive difference of the quantum information interpretation to other objectivist interpretations of QM.

But first let's again come back to the question in what sense the quantum information interpretation then is parsimonious compared with the Many Worlds interpretation. The answer is not only related to the 'substance', i.e. quantum information states instead of quantum states, which is used in either model, or what has to be assumed as domain(s) for storing the not observed quantum states, i.e. infinitely many copies of the observable universe versus a five dim bulk space, but this question is not less related to the way of 'operating' the intercourse of the observed and the not observed quantum states.

In the Many Worlds interpretation there is not much of such intercourse and there is also not much need for it, since the many different relative states are each one for itself realized as a (copy of the) proper universe. In the quantum information interpretation that intercourse is however managed as it should be in the case of information states, i.e. it is managed by projecting or mapping the respective quantum states from the surface forth to the bulk and then back to the surface or vice versa just as respectively required. And since the quantum information interpretation requires really very many of these mappings it could also justifiedly be called the many mappings interpretation of QM. And since mappings are undeniably less substantial than universes or ontologically much cheaper, the quantum information interpretation can justifiedly be seen as the looked for parsimonious relative state interpretation of QM.

It is then also this ontological 'lightness' or the prevalence of the informational aspect, which gives a slight indication in what sense the quantum information interpretation differs from other objectivist or ontological interpretations of QM, including the holistic interpretation of QM of David Bohm [22] resp. the later versions of that known as the quantum potential approach [23], which on the other hand shows also some features somewhat familiar to the quantum information interpretation.

The ontological difference of the quantum information interpretation to these and other objectivist or ontological interpretations has at least two different yet connected aspects. And these aspects are apart from the differences in the physi-

[21] And to be honest, if the quantum information interpretation will stand firm, that will also fully apply to the observable quantum states as well.

cal consequences, which are attached to them, of a genuine philosophical kind. I.e. they are related to the question, if the respective interpretations have a dualistic or monistic ontological setting and – far more interestingly than that – to the question, which of the various possible kinds of a monistic setting they imply.

Related to the first question the quantum information interpretation differs sharply from such ontologically utterly overloaded interpretations as the 'old' quantum potential (combined with the concept of a so-called 'objective collapse') once proposed by Heisenberg, which had been explicitly Platonistic and took that particular kind of quantum potential as the 'place' of preexistence of the totality of all quantum states, which ever had occurred, are occurring and will occur in the (history of the) universe. Since such Platonism doesn't play any role anymore in the interpretation of QM, it will do for that to make clear, that the quantum information interpretation has not the slightest tinge of dualism, but instead it is an utterly monistic approach to the interpretation of QM.

Yet that then doesn't mean, that 'monism' is such an unequivocal notion, as one should expect for a term referring to something so seemingly uniform. Furthermore the quantum information interpretation is also an actualistic interpretation of QM, it doesn't require or allow any pre-existence or pre-storing of quantum information states, which are not actualized or respectively concealed and by that instantaneously connected with the quantum states at the surface being observed or decoherent or respectively not observed or in superposition.[22] That instantaneous actualism of the quantum information interpretation is again directly due to the Holographic Principle.

And though not with respect to the question of dualism and monism then at least with respect to the question: 'What kind of monism?' the quantum information interpretation also differs strictly from the holistic interpretation and the later version of that known also as 'quantum potential'[23].

These partly identical interpretations are – at least intended to be – soberly monistic. However they widen or extend the ontological scope of physics by adding either new kinds of actions or – in the quantum potential approach – a domain or reservoir for hidden quantum states to be projected as needed. And that's fairly similar to the way the quantum information interpretation proceeds. But the result differs severely.

[22] I.e. there is no quantum potential required in the quantum information interpretation neither in the appalling Platonistic version once proposed by Heisenberg nor in the rather sober monistic way of the later versions of the holistic interpretation of David Bohm and Basil Hiley, since in the quantum information interpretation there must be nothing, i.e. no quantum state neither real nor virtual nor potential nor whatsoever, added or be presumed as preexistent. And the reason, why in the quantum information interpretation – quite as in the original relative state interpretation – nothing must be added in the end is, that from the beginning nothing is lost.

[23] Which should not be mistaken for that former dualist interpretation with the same name.

It differs with respect to the particular ways of widening or extending the ontological scope of the observable universe. The holistic as well as the quantum potential interpretation are definitely not observer-centric in any traditional way, but maybe being universe-centric is the very last bastion of being even involuntarily observer-centric.

The extension of the scope of the physical ontology of the observable universe goes in the holistic as well as the quantum potential interpretation in a way of as well embedding as permeating or pervading the substance of the observable universe with a kind of ethereal quantum-state-substrate, i.e. a nonlocally omnipresent aura in and of the observable universe and being in undivided communion with it. And also being as detectable as it fits for ethereal quantum substances.

The quantum information interpretation instead presupposes an orderly divided universe and – what makes even more of a difference to the otherwise philosophically not so unfamiliar sounding quantum potential interpretation – it is not universe-centric. Universes are in the view of the M-cosmologically prepossessed quantum information interpretation rather particular instances or occurrences in a more fundamental pre-universe(s) or hyperspace physics.

The particular way of dividing the universe is directly related to its beginning as a 5 dim space, which came into existence as a compactification in a 11 dim hyperspace, and of which then 'later' the 4 dim surface overproportionally expanded. The storage dump for the quantum information states correlated to the quantum states of the 4 dim surface part then is the 5 dim bulk part of the universe and that might perhaps justifiedly be called an 'inner aureola of the entire universe', but it could hardly be called an 'ethereal quantum substance', since it is just – meant to be – an ordinary chunk of (more or less) ordinary physical space. That is to say, that hyperspace ontology is more ordinary and sober than Hilbert space ontology.

The multidimensionality and higher dimensions D. Bohm and B. Hiley referred to, thereby explicitly pointing out, that it could go up to infinity, and which plays the role of the space of the ethereal quantum-state-substrate in the holistic interpretation are of course the dimensions of the Hilbert or quantum mechanical representation space, whereas the higher dimension required by the bulk space in the quantum information interpretation is not that of a representation space but of a 'proper' physical space. An *ontological* interpretation of QM however should then probably be better built in and based on proper physical space – though of an a bit advanced dimensionality – than being implicated in the infinite dimensionality of an ethereal quantum substance derived from ontified secondary attributes.

The monism of the holistic or the quantum potential interpretation of QM then is – as it should be expected – quite in accordance with their respective ontology, i.e. a widened or extended physicalistic monism, the proper substance of which consisting of the ordinary physical substrate of the observable universe as provided by the respective theories of high energy physics on the one hand and general relativity on the other, but also with this ordinary physical substrate somehow ‘completed’ by that pervading ethereal quantum substance of ontified Hilbert space states.

The monism of the quantum information interpretation however differs essentially from all of that. It is simply not a physicalistic monism and it is also not a sensualist, mentalist or idealist monism in any way. In philosophical terms the monism of the quantum information interpretation has, in my view, to be seen as a quite new and pretty strange kind of ‘neutral monism’. That is the name of a concept, which once had been introduced by Bertrand Russell [24], yet in a context completely different from that of the ontological implications of an interpretation of QM and also with a distinctively different meaning of ‘monism’ compared with that, what one has to expect in the case of the ontology of the quantum information interpretation.

The monism implied by the quantum information interpretation will have to be as objectivist as this interpretation claims to be and, since it also claims to be no physicalistic monism, it seems to have a somewhat hybrid nature, i.e. it seems just to be ontologically – somehow neutral. Yet a hybrid nature means sterility and neutrality sooner or later turns out not to be a stable position. Therefore being neither physicalistic nor subjectivist in any sense can only go together with a comfortable ontological position, when it can be – so to speak – substantiated, i.e. being founded in a respectively *neutral substance*.

Asking for a substance independent from any physical or – in the broadest sense – mental or subjectivist substance must appear quite weird or being a case of philosophical agitation, but interestingly enough the answer to this question is possibly a suggested implication of the Holographic Principle.

What I mean by that I can perhaps make at best clear by ‘demonstrating’ that, what I think the Holographic Principle eventually will do to the content of a well known statement of Rolf Landauer, namely “Information is physical” [25]. The Holographic Principle however is, in my view, the *first indication*, that Landauer’s statement eventually will have to be inverted and then go as *“Physics is informational”*, and that is of course not meant ‘informally’, but utterly ontologically.

And since the Holographic Principle, in particular in connection with that informational aspect, which sees quantum states – at least if vanished or not being observable – becoming equivalently quantum information states (in the bulk), plays such an important role in the quantum information interpretation, I therefore hold that the proper monism of the quantum information interpretation is an *informationmonism*.

Yet I will at once admit, that the assumption of an informationmonism being the ultimate ontological setting can not be sufficiently corroborated solely by referring to the Holographic Principle. The Holographic Principle just is, as I said above, a first indication that the ontology of an ultimate theory should be of such a kind. The domain of the possible corroboration of that hypothesis yet lies even beyond the domain of pre-universe physics but rather in the domain of the emergence of primordial partons up from 'something else' – i.e. something that could perhaps be called 'pre-physics'. [24]
Yet since an interpretation of QM should be concerned with the question of, where 'somewhere else' may be laid, and not with the question of, what 'something else' may be, I now should better leave this ontological speculation.
Talking of speculation, a quantum information interpretation should perhaps say something about quantum information processing. D. Deutsch recently [27] argued for the Many Worlds interpretation of QM by suggesting, that the expected effectiveness of quantum computation would be due to exploiting the computational capacities of the many worlds – taken literally. I think he pointed out something really important by that argument and I also strongly agree, that the expected effectiveness of quantum computation is further evidence against any subjectivist interpretation. This effectiveness then is also an indication, that quantum computation must have a reach to a resource somewhere beyond the reach of observation, or better: beyond the limits of the observable universe.
But then I would also hold, that quantum computation would work not less effective on – so to speak – a 4+1 dim 'bulk hard disk' than it would do on a sequence of copies of the (3+1 dim) observable universe in parallel connection.

And since we are run out of speculations for now, we will come to the end of this paper – with a bit of 'revisionism' attached.
The quantum information interpretation of QM as proposed in this paper has some rather unexpected implications. So it is intriguingly double faced with respect to the universal validity or significance of QM. On the one hand it absolutely uncompromisingly follows Everett's proposal, that the wave function (of the universe) designates a fundamental encompassing reality (of the entire universe, now consisting of a 3+1 dim surface part called the observable universe and a 4+1 dim bulk part, which could be called the 'dark (side of the) universe'[25]). And it also strictly follows Everett's proposal, that there are no objects, which are no quantum objects (in the entire universe).
But on the other hand it also seems to confine QM – at least with respect to the quantum phenomenology, which plays such an important role in the questions

[24] More about the possible relations between 'pre-physics', informationmonism and the mêontology of an ultimate theory can be found in [26].
[25] Which again might by some be seen as a more or less fitting paraphrase of 'inner aureola'.

concerning the interpretation of QM – to such rather incidental and particular objects as universes (including delicately combined ones) are or at least to such objects, which would satisfy the Holographic Principle, in a way comparable to the one proposed in this paper, i.e. for surfaces of up to 3 spatial dimensions. That obviously leaves some (hyper)space open for pre-universe physics, which doesn't relate to universes at all, i.e. – so to speak – for pre-compactification physics, which then would not necessarily show effects of quantum phenomenology comparable to such, which play a role in the EPR situation, at all.
These effects then could possibly turn out just to be something like an epiperipheral after-image of the intrinsic dualities at the core of M-theory. An after-image appearing after at first these dualities have been broken down to the 11 dim supergravity and then secondly this domain again becomes compactified to the 5 dim emergent integrated universe and then eventually actually emerging, when growing out of this 5 dim universe a 3+1 dim surface part comes up, called the observable part of the universe (and covering the 4+1 dim bulk part). And then the Holographic Principle would come into play as a kind of 'interface' – or projection area for what's eventually left of the original dualities – for the observer in the end.

This somehow leads me to a final remark. If the quantum information interpretation of QM proposed in this paper would turn out to be right, then this would consequently imply a rehabilitation of the consistently mocked at position of Einstein in the debate (with Bohr and others) about the interpretation of QM. The quantum information interpretation is thoroughly non-subjectivist, i.e. objectivist and therefore – in any reasonable sense [26] – 'realist' and it also doesn't require any nonlocal action taking place *in the observed part* of the universe. Yet it nevertheless strictly accounts for the nonlocal appearances or effects, which are observed. I.e. the answer to that question, which was the title of the famous article of Einstein, Podolsky and Rosen: "Can quantum-mechanical description of physical reality be considered complete?" [7] then would – at that historical time – have had to be a sounding "No!". Which incidentally is exactly the answer Einstein and his co-authors then suggested.
Yet in the light of the proposed quantum information interpretation this would have been the right answer not for the same reason, which had been assumed to be in question by all the participants in that original debate, namely that there either was something missing or not *on the side of the theory*, which then again would either way have had consequences for its ability to more or less perfectly or completely describe physical reality.

[26] I.e. *not* in an epistemological sense! For a more detailed discussion of epistemological, ontological and other aspects of anti-realism, objectivism and realism cf. [28].

But the answer would rather have had to be “No!” for the actually *not* deliberated reason, namely that there was something missing *on the side of the physical reality*, and not just a major chunk of knowledge about its pertinent (in)completeness, but – even worse – the biggest chunk of that physical reality itself.

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