Do confinement and darkness have the same conceptual roots?

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Abstract

In this note the connection between "perfect dark matter" and string-localization as the tightest noncompact localized matter is pursued in the context of Yang Mills theories. A programmatic approach based on the observation that behind the serious infrared problems which prevented the use of the axial gauge there is unique covariant semi-infinite string-like field, which fluctuates in the endpoint as well as in the string direction, is formulated and the open problems are explained.

Whereas hitherto the gauge formalism in its local gauge invariants accounted for the observed hadrons the new formalism based on the consistent use of string-localized vectorpotentials has a good chance to unravel the nonlocal part in which energy-momentum carrying dark/confined objects (gluons, quarks...) may be residing.

0.1 Positive energy matter with string-localized generators

In a previous paper the question of whether perfect dark matter (pDM) is consistent with point-like QFT was investigated [1]. Here pDM matter is a hypothetical positive energy matter which coexists together with standard matter is part of one joint theory but which cannot be created from collisions of matter as we know it. Hence the observational relevance of the present work depends on a null-effect in the planned DM creation experiments. As a result of the many connections to basic structures of QFT, in particular unsolved problems of gauge theory, some of the theoretical problems which pDM raises are also of an autonomous theoretical interest.

Our main finding in [1] was that it is not possible to emulate pDM if it would be, like standard matter, generated by point-like fields. The crucial theorem in this regard states that in higher dimensional QFT \((d \geq 4)\) it is not possible, barring the weird case of a doubled universe with photons which only couple to one tensor factor, to have a creation of exotic matter from standard matter if the exotic matter is also generated by point-like fields.
This directs the attention to semiinfinite string-like generated matter (SGM). Before we remind the reader of some old but little known rigorous results on this matter, it is necessary to emphasize (in case it was not noticed already) that string theory (ST) is not SGM [4]; in fact the quantization of the classical Nambu-Goto relativistic string leads to a point-like localized quantum field; the classical string degrees of freedom go into an infinite mass tower which is localized over the same point. With other words the characteristic feature of this model (as compared to standard QFT which results from the quantization of classical point-like fields) consists in an enormous spatial agglomeration of degrees of freedom over one point. Since the (graded in presence of supersymmetry) commutator is a c-number, the N-G ”string” field is technically speaking a ”generalized free field” with an infinite mass and spin spectrum [1]. As a result one finds all the properties of generalized free fields which quantum field theorists consider as unphysical as Hagedorn thermal behavior, breakdown of the time slice property [2] and other results of mental games for which there is no indication in nature.

The excuse (using Feynman’s reproach of ST) of string theorists, who have looked at the issue of localization, is that the string field only reveal the visible part of the string which only consists the c.o.m. point, i.e. they attribute an intrinsic meaning to the often classical way in which quantization is started [3]. This metaphoric way falls back behind Heisenberg’s notion of observables which was introduced just for the purpose of avoiding potentially misleading (quasi)classical metaphors. Every reader who understands the definition of SMG matter will not fail to realize that string theory does not deal with SGM. With this reverence to ST, we are now ready to continue our presentation of SGM without making appologies everytime we use the word ”string”.

QFT supports the existence of massive SGM, since the standard mass gap assumption which led to the derivation of (LSZ, Haag-Ruelle) scattering theory from the principles of QFT also permits to prove that the field sectors associated to local observables are at worst string-localized [3][1]; i.e. no ”branes” or other higher dimensional localizations are necessary to generate the full content of QFT. Of course one is free to to consider even in point-like QFT decomposable strings (and higher dimensional objects) by integrating point-like fields along strings/submanifolds, although there are no structural reasons for doing this (quantum interpretation of quasiclassical solutions,...)

But the theoretical research around this Buchholz-Fredenhagen theorem has been hampered by the apparent lack of perturbative insight; in addition it is very difficult to find any observable ramifications of these massive algebraic

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1. It would be interesting to understand whether the geometrically introduced interactions (splitting and recombination of tubes) admit a reasonable representation in terms of introducing interactions on generalized free fields.

2. Whereas it is true that a functional integrals or the canonical Lagrangian quantization are useful for constructing quantum theories, one has to be very careful to base conclusions about localization properties on functional integrands. Causal localization has a totally autonomous meaning on the quantum side [1] which accidentally agrees with the classical localization in the point-like case. Without this coalescence Jordan would not have had the chance to discover field quantization before Wigner’s 1939 intrinsic access to particles.
SGM in the energy-momentum spectrum and localization structure of particle states. The biggest on-shell change caused by strings is the breakdown of the crossing property\(^3\) and its corrolar, the Aks theorem \(^5\), which states that there can be no elastic scattering without particle creation.

This leaves the hypothetical possibility of pDM which cannot be created from collisions from ordinary (point-like generated) matter \(^1\). In fact the authors speculated at the end of their paper \(^3\) that this could be a field theoretic mechanism for confinement in the sense of a vanishing creation cross section for string-localized matter \(^4\). It is not far-fetched to assume that the authors at that time did not think in terms of pDM which seems to provide a stronger motivation for the absence of production via evasion of the Aks theorem. The apparent nonperturbative nature of BF strings has been an impediment to their exploration.

This leaves the possibility to start from string-localized zero mass free fields and study the perturbative interaction of such fields. The Wigner positive energy representation theory classifies such starting points, namely the countable family of finite helicity representations and the continuous family of “infinite spin” representations. Of these two families only the infinite spin family is \textit{string-localized as a representation} in the sense that there are no point-like generated subspaces.

The shortcomings of the use of such representations (possible lack of a point-like energy-stress tensor) for pDM have been presented in a previous paper \(^1\) where it was pointed out that the unusual properties of this kind of matter require equally unusual properties of the still elusive QG in order to couple in a mutually compatible way. So the string-localized generators of the infinite spin free field are nice mathematical illustration of perfect string localization and darkness, but they do not fit into our present picture of particle physics.

On the other hand the finite helicity family can be generated by point-like field strengths\(^5\) but there is a significant difference to the situation of massive higher spin field. Whereas the latter are described in the spinorial formalism by undotted/dotted fields of the form \(^7\)

\[
\Phi^{(A,\dot{B})}(x), \quad |A - \dot{B}| \leq s \leq A + \dot{B}
\]  

\hspace{1cm} (1)

where all infinitely many pairs \((A, \dot{B})\) in the given range are realized, the zero mass situation is only consistent with those (still infinitely many) special realizations obeying \(A = \dot{B}\). Luckily one can regain the lost possibilities by allowing string-like localized generators. Hence the important vectorpotentials for \(s=1\) and the metric tensor potential for \(s=2\) which would violate this rule

\(^3\)The on-shell crossing property requires the existence of pointlike interpolating fields for the respective particles.

\(^4\)In later work \(^6\) quarks and gluons were identified with ”ultraparticles” i.e. objects which do not exist in the actual theory but rather in a canonically associated scaling theory.

\(^5\)The electromagnetic field strength for \(s=1\) and the 4\textsuperscript{th} order tensor field strength (with the tensor symmetry of the Riemann tensor) for \(s=2\) and the related vector- respectively metric tensor- potential.
are described by string fields $A_\mu(x,e)$ and $g_{\mu\nu}(x,e)$ which are localized on the semiinfinite string $x + \mathbb{R}_+ e$.

\[
(\Omega, A_\mu(x,e)A_\nu(x',e'))\Omega = \frac{1}{(2\pi)^{3/2}} \int d\mu(p) e^{i(x-x')p} M_{\mu\nu}(p;e,e'),
\]

\[
d\mu(p) = \text{measure on } \partial V_+
\]

\[
M_{\mu\nu}(p;e,e') = -g_{\mu\nu} - \frac{p_\mu p_\nu (e\cdot e')}{(e\cdot p - i\varepsilon)(e'\cdot p + i\varepsilon')} + \frac{p_\mu e_\nu}{(e\cdot p - i\varepsilon)} + \frac{p_\nu e_\mu}{(e'\cdot p + i\varepsilon')}
\]

\[
(\Omega, g_{\mu\nu}(x,e)g_{\kappa\lambda}(x',e')\Omega) = \frac{1}{(2\pi)^{3/2}} \int d\mu(p) e^{i(x-x')p} M_{\mu\nu\kappa\lambda}(p;e,e')
\]

\[
M_{\mu\nu\kappa\lambda}(p;e,e') = M^R_{\mu\sigma\nu\tau\kappa\alpha\beta}(p) \frac{e^\sigma e^\tau (e')^\alpha (e')^\beta}{(e\cdot p - i\varepsilon)^2 (e'\cdot p + i\varepsilon')^2}
\]

Here the summation convention has been used and $M^R$ stands for the two-point function of the point-like spin 2 field strength (a 4th degree homogeneous polynomial in $p$) which is identical to that of a linearized Riemann tensor. These string-localized fields are covariant in the sense that the string direction $e$ transforms under the homogeneous part of the Poincaré group. Free string-like potentials (from which one obtains the point-like field strength by differentiation) can also be directly written in terms of explicitly calculated interwiner $u(p,e)$.

The full $(A, B)$ spectrum can be recuperated by allowing string-localization; furthermore string-like localization for both massive and massless spin $s$ fields are expected to overcome the van Dam-Veltman No-Go theorem for approaching massless linearized gravity from its massive version via point-like fields.

Different from the gauge theoretic setting, the string-localized potentials are operator-valued distributions in both $x$ and the spacelike unit vector $e$ i.e. the field fluctuates in both, so $e$ does not behave as a gauge parameter but as a localization point in 1+2 dimensional de Sitter space. Although there is no variation along the string, the situation is not that of an object “living” on the tensor product of the Minkowski spacetime and the 3-dim. de Sitter space of spacelike unit vectors $e$. In other words the commutativity of the strings is not following the rules of a tensor product of Minkowski- and the de Sitter- space but is rather decided by the spacelike separation of the two semiinfinite strings $x + \mathbb{R}_+ e$ and $xt + \mathbb{R}_+ e'$.

An important property which makes a field description fit for perturbative renormalization is its short distance scale dimensions (sdd). Although the field strengths have $sdd \geq 2$ which increase with helicity and are already for $s = 1$ above the power counting limit, the sdd of the potentials stays at the smallest possible value namely $sdd = 1$. The metaphoric explanation of this phenomenon is that the linear transition from point-like field strength to string-like potentials by formal integrations along a seminfinite line encodes part of the short distance fluctuations into directional e-fluctuations i.e. into Minkowski space infrared fluctuations (which are short distance in the de Sitter sense).
The short distance improving feature of string-localization is of course also effective for massive fields. In that case even the s=1 vector field has $sdd = 2$ which surpasses the power counting limit; string-localization brings it back to renormalization friendly value $sdd = 1$. Only if one starts from zero mass the Schwinger-Higgs screening mechanism is implemented: the complex scalar field with the wrong sign of the mass term is converted into a point-localized neutral field instead (as for a usual mass term) of a delocalized (with string-localized generators) charged field surrounded by photons. But a calculation which starts with free massive vectormesons and forces them to lower their $sdd = 2$ to $sdd = 1$ by combining them with massive BRST ghosts (i.e. using the sdd improving aspect of the BRST setting which is not restricted to gauge theories) shows that the Schwinger-Higgs screening picture is a helpful metaphor for the apparent necessity that interacting point-like local massive vectormesons apparently must be accompanied by a scalar massive companion (naturally without requiring a "vacuum condensate" thus reducing the Higgs phenomenon to the well-known locality principle. A formulation in terms of a string-localized massive vectorpotential without BRST ghosts (and naturally without Higgs condensates for which there is no purpose in a perturbative approach which starts already with "fat" vectormesons) would remove the remaining doubts about whether the Higgs phenomenon is part of a more intrinsic phenomenon that massive higher spin objects (in this case s=1) require the company of lower spin companions (in this case s=0) in order to uphold locality.

Returning to the zero mass vectorpotentials, it is not difficult to see that the string-localized vectorfield is formally identical to the axial gauge as a result of the second of the two relations $\partial_{\mu}A_{\mu}(x,e) = 0 = e_{\mu}A_{\mu}(x,e)$. But the construction of string-localized fields has nothing to do with gauge fixing; it is rather the result of the existence of a string-localized vectorpotential which is the only covariant vectorfield in the Wigner-Fock space. A closely related remark is that since the string-localized potential lives in the physical Wigner-Fock space, there is no reason for removing unphysical ghosts; at this point it is also helpful to remind oneself that the gauge setting does not really address symmetries but rather converts a redundancy resulting from enforcing an apparent point-like description via the BRST formalism into a (false from a physical viewpoint) symmetry so that the perturbative physics can be retrieved via the associated cohomology.

Finally one should also point out that the axial gauge has only been used in formal canonical arguments and never successfully in a perturbative renormalization approach; it is well-known that any attempt failed as a result of severe infrared divergencies. The string-localized field "explains" the origin of this problem in terms of fluctuations of the string direction and indicates (see the next section) how to formulate a new renormalization theory which takes care of string fluctuations.

For experts of local quantum physics who are familiar with the content of

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6. This vaguely resembles particles to come in multiplets in the supersymmetric setting of QFT except that in the present it is the locality principle and not group theory which groups particles together.
Haag’s book [12] it may be interesting to point out that, whereas the local algebras \( A(\mathcal{O}) \) generated by massive free fields are Haag dual for arbitrary connected causally complete regions \( \mathcal{O} \), this does not hold for the algebras generated by zero mass field strengths where the duality only holds for simply connected region but is violated for multiply connected \( \mathcal{O} \)s [13]. In such a case the algebra associated to the multiply connected region has more operators than those which can be locally generated within that region. The existence of string-localized potentials in some way “explains” this phenomenon [9].

1 Towards a perturbative renormalization for massless string-localized vector potentials

The only interacting string-localized QFT which has been reasonably well understood in terms of a perturbative renormalizable gauge setting is QED. In the standard treatment where one uses Feynman rules for the gauge dependent point-like matter and vectorpotential field the string localization is not yet visible but any attempt to define a physical charged field shows that this is only possible by excepting delocalization. The best one can do (in the sense of sharpest localization) is to define semiinfinite string-localized charged fields of the Jordan-Mandelstam form

\[
\Psi(x, e) = \psi(x) e^{i e \int_{x' = x + R, e} A_\mu(x') dx'^\mu}
\]

\[
\Psi(x, f) = \psi(x) e^{i \int f_\mu (x - x') A_\mu(x') dx'^\mu}, \quad \partial_\mu f^\mu(x) = \delta^4(x)
\]

Steinmann has succeeded to show that this formula (in the smearing sense of the second line) can be given a rigorous perturbative meaning. His arguments are quite tedious and involve a new organization of perturbation theory; the reader is referred to his paper [14].

Less string-like and more Coulombian smearings leads to other less covariant delocalizations. Common to all physical charge carrying operators is the infra-particle nature of their energy momentum spectrum which consists of a mass-shell singularity which (due to the very strong interaction of charged particles with infrared photons) has been sucked into the photon continuum, a fact which can be most easily observed in the Kallen-Lehmann representation of the two-point function of the charged field. The spectrum starts at the alias mass shell \( p^2 = m^2 \) with a sub delta function power behavior which is characteristic for infraparticles (which were recently rediscovered and called unparticles). These infraparticles are despite their string-like localization the best “candles” of particle physics, they consist of a hard nucleus which however cannot be separated from its soft photonic halo which is responsible for the delocalization and at the same time for the continuous emission of infrared photons.

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7In Rumsfeldian terminology this is the best example I know for illustrating what means an “unknown known” in QFT.
One could be satisfied with this gauge theoretic description if it would not be for the fact that the construction of the physical charge fields has to be done "by hand". A formula as the above one is not suggested by an intrinsic canonical procedure of the Lagrangian or causal approach but rather is a desperate attempt to define and control the most important objects of QED namely the charged particles and their physical properties.

This ad hoc way becomes a serious problem in the case of nonabelian gauge theories. Take the simplest case of SU(2) gluons; it is impossible to find any perturbatively renormalized mathematical controlled proposal for a gauge invariant nonlocal object, one only knows how to formally construct point-like gauge invariant gluonium composites and their may be people who convert their inability to come up with a conjecture into the far-fetched claim that there are no nonlocal gauge invariants in nonabelian theories. Hence one would like to have a setting in which such problems can be addressed in a more natural way.

This background is the main point of departure for a new pragmatic approach to string localization and in particular to the problem of a possible string-localized matter content of Yang-Mills theories which may carry unobserved but gravitationally relevant energy-momentum.

The point of departure of a perturbative attempt is this direction are the string-localized covariant vector potentials obtained from the Wigner representation theory. In the following (as well as in previous work) "string-localized" always refers to generating fields $A(x, e)$ which are localized along a spacelike half-lines $x + \mathbb{R}_+ e$.

A formulation of perturbation theory in which causal localization plays a central role is the Stueckelberg-Bogoliubov-Epstein-Glaser setting also referred to as "causal perturbation theory". Its input is a point-like scalar composite field (the interaction Lagrangian) $L_{\text{int}}$ which is a Wick-ordered polynomial in free fields. For the case at hand these free fields may also be string-localized vectorpotentials $A_\mu(x, e)$. As in recent treatments of gauge theories and QFTs in CST it has been customary to limit the interaction to a compact spacetime region in order to concentrate on the algebraic structure and avoid infrared problems caused by the inappropriateness of global states in the perturbative Wigner-Fock space. The construction is inductive i.e. knowing the time ordered product of $n$ $L_{\text{int}}$ one tries to determine the $(n + 1)^{th}$ order including an explicit parametrization of the possible ambiguities (renormalization). The most important concept in this step is the causal locality and the notion of a minimal scaling degree. For point-like fields in Minkowski spacetime the validity of translational invariance greatly simplifies the determination of the ambiguity: as a result of its support on the joint diagonal on the $n$ spacetime points it only involves (derivatives of ) delta functions and the requirement of a minimal scaling degree limits the degree of the delta functions. In the case of CST the

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By honoring this historical notation we do not want it to be misread as being part of a Lagrangian description. In causal perturbation theory, different from the functional integral setting, there is no need for a Lagrangian formalism and most of the different ways of relating the unique Wigner theory with a covariant spinorial description are not of the Euler-Lagrange type. This approach is intrinsic i.e. not dependent on any Lagrangian parallelism.
lack of translation invariance makes the discussion more involved; in particular the minimal degree implementation requires the analysis of a degree associated with submanifolds with the help of microcausal analysis.

The complication of lack of translation invariance does not occur with string-localized fields, but the time ordering of strings and the problem of the minimal scaling degree is more involved. The string-configurations which violate the causal separations in the sense of Bogoliubov turn out to form an open set whereas in the point-like case they just consist of a point (the complete diagonal) problem at hand namely renormalization involving string-localized fields requires a generalization which is presently under investigation. Since in that case even in the presence of translational invariance the problem of time ordering is rather involved (the strings which are in the causally non-separated position in the sense of the Bogoliubov approach form an open set instead of a point).

There are simpler subconfigurations which are characterized by a timelike vector for which the strings lie in a 3-dim hyperplane where it is clear that the mentioned Bogoliubov region consists of strings which are mutually included. These restriction of correlations to such subregions make sense if the distributions in $e$ allow a restriction to a 3 dimensional hypersurface (corresponding to a 2-dimensional de Sitter subspace) which seems to be the case. The general situation may then be build up by starting from these subconfigurations in $\mathbb{R}^{n(4\times3)}$ and their scaling degrees. A programmatic sketch is however no substitute for concrete results.

There is a significant difference between the QED type situation where vectorpotentials are coupled to (massive) matter fields of $s \leq 1/2$ and the Yang-Mills type mutual interactions between vectormesons and possibly interactions with low spin matter fields. In the first case the point-like locality between a free string-like vectorpotential and its linearly related field strength is preserved in interactions since the directional dependence from internal vectormeson propagators can be (by partial integrations) removed, using the fact that the directional change is of the derivative form and drops out after moving the derivative to the conserved current (pretty much as in the gauge setting). The correlation functions involving matter fields on the other hand will have a directional dependence through radiative corrections and by forcing the directions in the above indicated way into a small neighborhood around one preferred direction as mentioned before, we describe a situation similar Jordan-Mandelstam formula \(\text{(4)}\).

The Yang-Mills situation is totally different. In that case the requirement to find a point-like subalgebra for a theory of interacting string-like vectormesons is very restrictive. Already the requirement that the spacetime integral over $L_{\text{int}}$ is formally directional independent leads to a restriction which however does not yet secure the existence of local subalgebras generated by nonlinear composites. In fact, taking a hint from the gauge setting, the additive change under a directional change in the free case should change and the higher order contributions should build up to a multiplicative rotation in the component space of the vectormesons with a composite field of $4^{th}$ degree being the lowest point-like composite. There is no group theory ”by hand” involved here, since
the only principle one has in this setting is the existence of local observables within a setting of coupled string-like vectorpotentials; i.e. the gauge classical "crutches" have been lost. Last not least, this method should produce non-local gauge invariants for which the "by hand" method failed.

We expect that the gauge- and the string- setting coalesce on the local observables \[18\][19], and we anticipate that the limitation of the perturbation theory to the construction of the local algebras and its ineptness for the construction of states is common to both approaches.

The new approach should be first tested in QED because in that case we already know a lot about string-localized generators from the mathematical reformulation of the Jordan-Mandelstam conjecture. The advantage of such an approach is obvious, the construction of electric charge-carrying operators is intrinsic and not done by hand i.e. it does not depend on the ingenuity of guessing gauge invariant nonlocal expressions.

2 String-localization, confinement and darkness

The fact that electrically charged infraparticles are our best "candles" shows that it is ill-advised to base a DM description on the energy-momentum spectrum which is identical to that of the "unparticle" proposal \[15\][16]. Since pDM can only occur in string-localized sectors and since we (at least temporarily) rejected the only explicitly known model namely the string-localized energy-momentum carrying infinite spin field on the ground of its apparent extreme inertness (even with respect to semiclassical Einstein-Hilbert gravity), our search will be narrowed to (excluding higher helicity matter) self-interacting massless vectorpotentials.

What lends additional importance to such a search is the fact that virtually nothing is known about possible nonlocal gauge invariant sectors of Yang-Mills theories. To believe that the nonlocal gauge-invariant richness generated by gauge invariant string-localized operators suddenly disappears and only local gluonium and hadronic matter remains, is not very palatable, although some particle theorists seem to have accepted this view.

Most particle physicists consider quarks and gluons as practically useful but conceptually unresolved metaphors. Others refer to the scaling limit of QCD which they imagine to be a free point-like theory of quarks and a collection of free gluonic field strengths. At this point usually the reference to asymptotic freedom enters. But one should keep in mind that the asymptotic freedom statement is a consistency statement and not a theorem\[9\]. Even if one excepts it as a theorem, it would not solve the problem about the reality content of QCD which in the present context amounts to the possible existence of non-local string-generated

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9This was the point view of Kurt Symanzik who prepared the ground for the perturbative asymptotic freedom calculation. Whereas e.g. in the O(n) Gross-Neveu model asymptotic freedom is a genuine property that model, in QCD this property refers to the consistency between the unknown confinement, whose renormalization group parameter space are the physical masses (coming from an ill-understood mass transmutation), and a perturbative accessible short distance phase in terms of a not directly observable coupling g.
sectors in Yang-Mills theories. At this point the searches for pDM and a better understanding of confinement of gluons and quarks coalesce.

Despite its unsolved infrared aspects, the axial gauge still enjoys popularity in canonical arguments [11]. It is our conviction [9] that these difficulties will be overcome after realizing that one is not dealing with a gauge fixing but rather with a unique covariant string-localized potential in a physical Hilbert space i.e. when one treats these fields as fluctuating in a bigger space as explained in the previous section.

Whereas for the determination of the renormalization freedom (thinking about a causal Epstein-Glaser approach extended to string fields) one needs to leave the string position (with the number of independent string directions which increases with the perturbative order), for the physical interpretation one wants to construct the sharpest localized generators by limiting the directional vacuum fluctuation via a compactly localized test function around one chosen direction as in [11]. So the first application of the string-localized formalism should consist in re-doing a Steinmann like calculation but without writing down a Jordan-Mandelstam Ansatz for charged fields by having the charged fields emerge from the renormalization formalism.

Whereas in the QED one has clear expectations about the string-like formalism being generated by charged particles whose permanent infrared photon-dressing can be compressed into an arbitrarily thin spacelike cone (from where one may generate more spread out nonlocal situations), the same cannot be said about Yang-Mills like models in the new formulation. The fact that the relation between local observables and string-like building blocks [10] becomes nonlinear, forecloses any attempt to visualize the strings as line integrals over (e-independent) local observables. In this situation the expected larger Hilbert space can not be arrived at by applying local observables; the model will have additional physical delocalized "stuff" generated by acting with the interacting vectorpotentials onto the vacuum.

It is this faith that behind the barriers of the infrared divergent axial gauge setting of Yang-Mills models there is a new string-based formalism [17], which supports our conjecture that confinement and darkness may be connected. Surely if there are nonlocal generators (in the gauge setting: nonlocal gauge invariant composites which cannot be obtained from local gauge invariants), i.e. if the phenomenon of string-like generation is not limited to abelian theories, they must carry nontrivial energy-momentum, and since the observed QCD spectrum covers all the seen particles, consistency demands they must be string-generated and dark.

Some messages can be abstracted from existing perturbative calculations based on the BRST gauge setting [18][19]. These are perturbative approaches

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10Since the computations have not yet been done, we cannot exclude the case that string-localized potentials can only be used to construct the perturbation theory of locally observable composites. The resulting situation would rule out the use of self-coupled vectormesons for the construction of interacting string-localized matter and pDM, but it would be interesting in its own right since it may lead to a theorem about the existence of QFT whose only connection to Lagrangians is via composite fields.
which separate the problem of the construction of the local algebras from that of states. About the second which includes the particle content and scattering theory, one can presently say nothing apart from the statement that these problems are outside of perturbation theory (at least for YM models). However, as shown in the two papers, the local algebraic structure can be perturbatively accessed. This turns the problem of finding the physical states into the mathematical problem of constructing certain states on operator algebras. The string-localized setting is expected to come with the same problems apart from the fact that it is expected to do much better on producing nonlocal (string-localized) interacting operators.

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