A SPECULATIVE ONTOLOGICAL INTERPRETATION OF NONLOCAL CONTEXT-DEPENDENCY IN ELECTRON SPIN

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1st October 2002

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Abstract

Intrinsic spin is understood phenomenologically, as a set of symmetry principles. Inter-rotations of fermion and boson spins are similarly described by supersymmetry principles. But in terms of the standard quantum phenomenology an intuitive (ontological) understanding of spin is not to be expected, even though (or rather, because) a spinor can be described as the most elementary mathematical object in quantum theory. This essay asks if it is possible, in principle, to have an intuitive model of intrinsic spin. The conclusion reached is that it is possible, given that an intuitive ontology is not necessarily a local/classical ontology. Some implications that might follow from requiring an ontological interpretation of intrinsic spin are explored. As an heuristic device, a toy conceptual model is developed in which paired spinors label states of a rotational symmetry internal to *non*local elementary quantum objects. The basic condition for these objects is that position becomes a locally two-valued elementary parameter. Essentially this can be seen as invoking an additional basis state for many-particle systems which would allow electron 'intrinsic spin' to be treated uniformly as a broken phase of a *nonlocal doublet* symmetry. It is shown that this leads to a simple and elegant way of visualising Pauli exclusion and to a dynamical view of electron 'shell' structure. A hidden 'superspin' parameter, invoked to carry this (generally broken) nonlocal symmetry, would have implications for a general ontology of quantum measurement.

Although the focus here is on electrodynamics, the idea can also be described as a generalisation of 'dynamical supersymmetry' from the interacting-boson model of nuclei, applied to electrons and photons. The new (broken) symmetry would be carried as a super-rotation of a photon, implying that supersymmetry is a latent property of the already-known particles of QED and that it should therefore be possible to associate its anticommuting algebras to differently symmetrised doublet properties of their interactions. But a generally nonlocal superspin symmetry of this type could not simply be attached as an add-on to a local metric manifold. It is suggested that the breaking of a dynamical supersymmetry in QED might be identified with the emergence of the Poincaré spacetime symmetry group. According to this idea a doublet superspin state becomes non-degenerate in a pair of position states, and this lifted degeneracy is ontologically prior to translations in flat SR spacetime. Moreover the resulting network of paired states can be characterised by saying that it puts particle quanta and space quanta into correspondence with one another through a general quantisation condition the essence of which is the discreteness not of scale or of volume but of direction[2] Such a radical vectorial discreteness implies no homogeneous field of scalar point functions, which fights against GR but is consistent with the fact that the Dirac

2 This indicates an obvious affinity with the spin-network programme. Later it will be suggested that in its most general form the present rough proposal could be characterised as seeking a radically scale-free 'inflationary' phase of an exhaustively-connected nonlocal *superspin*-network.

spinor is difficult to incorporate into Riemannian techniques. The essay argues that, in principle, a heuristic model could be developed along these lines with enough triviality to survive at least the constraints imposed by SR and standard QM. Some specific heuristic advantantages are also indicated in relation to a possible future theory of gravity and large scale cosmic structure. But it is also pointed out that it should be possible to falsify the class of such models easily by (among other things) the detection of a single gravitational wave event, a single sparticle, or a single Higgs boson.

Part 1 reviews the broad historical context of spin correlation in theory and experiment, and summarises why an intuitive ontology of electron spin (in particular) is unavailable in standard quantum mechanics. The meaning of spin eigenstates is also discussed from the point of view of Bohmian nonlocality arguments for comparison. Bohmian electron spin has a well-defined ontology; but it is not intrinsic. However it is argued (qualitatively) that an intuitive understanding of intrinsic spin eigenstates *is* possible if it is accepted that EPR spin correlations are a special case of a generally nonlocal property of quantum systems which doesn't appear explicitly either in the standard phenomenology or in a Bohmian ontology. Several of the conclusions that support such a point of view can be argued from perfectly conventional grounds, and indeed have been. However it is proposed here to recover spin correlation from a broken generalised spin symmetry as a restricted case.

In *Parts 2 - 5* the breaking of this generalised 'superspin' symmetry is given a physical interpretation in terms of a conceptually radical ontology. This would allow spin to be 'understood' intuitively by relating polarisation direction to an underlying quantum-spacetime structure in a novel way. This structure is a network of linear 'objects', whose first simple condition is that *each end of every 'object' is connected by one object to each end of all other objects*. In short the connectivity of the network is (unlike the generality of space networks considered in quantum gravity theory) exhaustive and completely scale-free at all epochs. A second condition is that each object carries local quantum labels only on its ends; and it is shown that such objects need not then conflict with SR because when a 'string' of such objects self-interacts it obeys an automatic self-consistency condition. This heuristic device is tried out qualitatively on the phenomenology and epistemology of spin measurements. However the implications seem to be quite general.

Very briefly (see especially *Part 4*), the unbroken or 'unfolded' superspin phase of this string is an inflationary mode. When folded on itself the scale-free repulsion gives rise to an 'attractive' short-range nonlinear inflaton self-coupling from the *form* of the folding which suggests (in a general way) that superspin could be seen as a restoring force dual with 'curvature' in an effective field theory of gravity. It is argued that once this network structure is 'understood' then the possibility of a novel quantum ontology can be said to have been (in principle) 'understood'. *Part 5* discusses the status of the field in such a scale-free network ontology. In conclusion, *Parts 6* and *7* then draw out some interconnections with transactional QM, absorber theory, spin networks and loop gravity, but I try to show where the quantum ontology suggested here would have distinct implications. Of particular interest is a model of Newtonian gravity proposed by Consoli and Siringo [1] based on a phase transition in a Bose-Einstein phion condensate, whose phonon excitations would be equivalent to Higgs particles in a spontaneous-symmetry-breaking vacuum model. It is claimed that the present discussion represents a sketch of a non-perturbative non-field approach which may be dual with the underlying nonlocal field theory in their model. Some rather general predictions of the present theory are indicated, mostly negative and qualitative.

1. Spin Correlations as a Restricted Symmetry Group

i.) There are several avenues of proof that nonlocal correlations exist in quantum mechanical system and they have been studied extensively in systems of small quantum number. It can be shown that nonlocal connections are generally the dominant type of connectivity in quantum systems. To say that the meaning of this fact is unclear in terms of any presently debated ontology would be an understatement. Nevertheless certain nonlocal correlations involving particle spin are well defined and well understood phenomenologically. The logical rationale for exploiting spin measurements as a test of nonlocal correlations was set out by Einstein, Podolsky and Rosen [2] in 1935 and developed by Bell [3,4], leading to the experiments of Freedman and Clauser [5] and then of Aspect *et al*. [6] demonstrating EPR-type correlation of photon polarisations outside the light cone. A general proof by Mermin [7], which does not rely on subtle statistical arguments to demonstrate violation of the Bell inequalities, extends Bell's theorem to systems of three spatially separated particles by showing that the eigenvalues of the individual spin operators are not independent of one another, in a way that is not consistent with the assumption of local hidden variables.

ii.) The ontological interpretation of quantum mechanics proposed by Bohm & Hiley [8] offers a useful summary of the theoretical status of spin for our purposes. Their discussion of the above issues leads them to conclude that the wave functions of systems of particles must *in general* be considered to be strongly, i.e. nonlocally, context-dependent. They draw attention to the fact that the antisymmetric wavefunction for a pair of fermions subject to the Pauli exclusion principle is a special case of an EPR-type wave function, and argue that even in the simplest cases spin cannot be regarded as an intrinsic particle property but emerges in an essentially participatory 'measurement' process. This conclusion is consistent with experimental evidence that if an electron were a spinning particle it would have to have a radius of $<10^{-16}$ cm, which would imply superluminal peripheral velocity to obtain angular momentum $h/4\pi$. With regard to larger systems Bohm & Hiley further point out that the number of independent spin parameters of the wavefunction for n particles increases as $2^{(n+1)}$ whereas individual particle properties can only increase as n. In many-particle systems, therefore, spin determinations depend on a huge number of terms which have nowhere to live if they are regarded as having physical correlates attached to particles. 'There is no way,' they conclude, 'to give a physical meaning to all the parameters . . . . One might consider properties belonging to sets of 2, 3 or 4 particles etc., but it is difficult to see what this could mean physically. Such properties would be nonlocal and might be significant even when the particles are far apart. In any case the simple model of a set of spinning particles would no longer apply.' [9]

iii.) Since their ontology requires a discrete particle with a deterministic (if unobservable) trajectory Bohm & Hiley are driven to conclude that an electron is a point particle whose only intrinsic property is its position, deriving spin angular momentum from an additional circulatory component of orbital motion. This interpretation requires the concept of 'active information' to supply the guidance condition for a neo-classical mass point according to the form (but *not* the amplitude) of a new quantum potential related to the de Broglie 'pilot wave'. [10] In the form developed by Bohm this new quantum field has vanishing energy and cannot do work; hence the source of the acceleration of the particle mass is sought separately in the vacuum energy, which can be surmised to have structure hidden in the seventeen orders of magnitude between the Planck scale and the finest present measurements.

iv.) These conditions might be thought a large cost for an intuitive picture of intrinsic (or in fact, in this case, extrinsic) spin, unless there is a strong attachment to the concept of an electron as a point particle; and even then the notion of position as an 'intrinsic property' of a point remains difficult, given that position must be *the* canonical context-dependent parameter. Alternatively one might attempt to address the paradox that electron 'intrinsic spin' is not an intrinsic property of a particle by supposing that 'an electron' is not a particle at all - i.e., neither a classical extended particle *nor* an infinitesimal point. Traditionally attempts to avoid the infinities of the latter have run into the locality problems of the former; but there is a sense in which these are technical issues beside the fact that an overall lack of intelligibility accompanies *any* kind of elementary 'object' in a probabilistic quantum theory. A great deal of theoretical and experimental development lies behind the QM phenomenological view that, for all practical purposes, a quantum particle is a group of observables whose only commonality is an association with a narrow peak in some root mean square distribution of probabilities, and although string theories negotiate the locality and infinity difficulties of points and blobs, they nevertheless work inside standard QM and succeed in mimicking the traditional conception and function of a QM particle so well that the ontological intelligibility of a probabilistic superstring is essentially the same as that of a traditional probabilistic particle. So the 'measurement problem' is addressed in Bohmian theory by a new nonlocal quantum field but measurements are still made on unintelligible point particles; whilst string theory has intelligible particles but remains at the mercy of the measurement problem. But what about a model which is *less* successful than either superstring theory or Bohmian theory at preserving free particles and quantum fields? Might a radically different kind of extended elementary object *more* successfully interpret nonlocal spin entanglement and the meaning of QM measurement along with it?

v.) Continuing optimistically and in a heuristic spirit one can ask the question: 'Can intrinsic spin be preserved as an intuitive property by associating it to an ontological element that is *not* particle-like?' The answer offered here is that it can, provided that 'an electron' is *in*completely defined by just one position variable, and completely defined (as regards extension) by two, and that this binary position state is generally, but covertly, *shared* between pairs of electrons, irrespective of scale, in the exact sense of a wave function which is symmetrical in the two coordinates. In this way it becomes possible to resolve the paradox of an 'intrinsic position' which is inherently relational. In outline, the hypothesis will be that the nonlocal symmetry describing this binary state is a universal EPR-type spin correlation which is in general broken in the emergence of Lorentz invariance, but in such a way that the hidden 'superspin' operates as a hidden variable 'internal' to the quantum electrodynamical interactions of what QM characterises as pairs of electrons, spin therefore being intimately related to a primitive conception of 'distance' underlying that of metrical space. Of course, if a Bohmian theory seems a large cost, then this approach probably threatens an even larger cost and may not in the end lead to models that prove well-defined. On the other hand QM itself is presently not well-defined and in fundamental respects - i.e., nonlocality and relativistic causality, gravity, measurement etc. - is neither lucid nor integrated. It may be that a radical shift of principle is necessary for it to become well-defined. Deotto and Ghirardhi [11] have shown that an equivalence class of Bohmian deterministic particle theories in fact contains an infinite number of empirically equivalent such theories. Whilst this complicates one's attitude to the uniqueness of Bohm's model and the falsifiability of nonlocal field theories in general, it may also prompt reflections on the true uniqueness of standard QM. Indeed Rohrlich and Popescu [12] have shown from general principles that QM is only one of the class of possible theories that combine nonlocality and relativistic causality in consistent ways and they therefore follow Shimony [13] in asking: what is the *additional* 'simple and fundamental principle' missing from QM which selects it from the class of such theories as the unique theory? One 'fundamental' and 'missing' principle which immediately springs to mind is the quantum gravity principle. Taking one's lead from Ghirardi, Grassi and Rimini [14], Penrose [15,16] and others who argue that gravity is needed to understand the reduction of the QM state vector, one might speculate that these were questions in search of the same answer. Then, one possible answer might be the principle that elementary 'position' is not a single-valued quantity on a metric manifold but is a two-valued quantity on a network. This can be expressed in the idea that the quantisation condition of spacetime is not one of position but of *direction*. Clearly there are several large claims here which need to be justified, at least in principle, before any detail need be considered.

vi.) As a probabilistic variable conjugate with momentum, position nevertheless has a precise meaning in standard QM. A narrow enough peak in the distribution of probable positions maps a point-electron's position to arbitrary accuracy in the limit of infinitely uncertain momentum. According to QM all that can be known about an electron's position is contained in the wave function. Classical assumptions about the particulate nature of elementary objects are imported, however, in that locality arguments are applied to classical blobs, reducing them to dimensionless points with the result that 'position' is held to be single-valued quantity. This assumption can be said to be justified by its success over a huge range of theoretical and experimental experience. Indeed, how can an elementary position function *not* be single-valued? Even string theories approximate single-valuedness of position to a high degree of accuracy on atomic length scales. (Uncertainty then introduces fuzziness, but this is not what we might mean by a radical many-valuedness of position.) Many-valuedness of position *is* possible, however, consistently with the locality conditions of measurements made at 'points'. For example, string theories preserve classical locality constraints without making the ultimate reduction to point-particles for reasons that in principle *can* be (but aren't) applied free of scale (i.e. prior to a 'background' manifold), and it is possible to imagine, in place of swarms of pseudo-particulate string loops, structures of nonlocal objects which each have more than one local position value, and which are topologically elementary, and which yet exist on arbitrarily *large* scales. Conditionally, this need not conflict with SR. (See *2.v.- ix.* below) Then if, for example, elementary local position turned out to be double-valued it would be the case that what the wave function maps as one peak in the distribution of probable position is an abstraction, and the group of observables associated to this peak should actually always be associated to a pair of such peaks along with another group of observables. One would then say that the half-unit of quantum spin attached at one electron position is *always* to be complemented, *via* some broken general symmetry, by a half-unit attached at another - as it is sometimes found to be *via* a residual restricted symmetry. In this way what QED would call a two-electron wave function becomes a special case of the fundamental entity, because a particle is *in general* only one end of a nonlocal elementary 'string'. (Note that a more detailed justification for the idea introduced here is given beginning in *Part 2*.)

vii.) The connection to standard QM here is easy to make. Linden and Popescu [17], Popescu and Rohrlich [18] and others have shown that the quantum state of any typical ensemble of large *n* is overwhelmingly characterised by the entangled relationships. QM requires that any many-particle system be represented by a single wave function which contains all the possible position states interdependently - to the degree that a 'many-particle' system becomes a self-contradiction - and the primitive connectivity of any system of particles naturally resolves into some number of pairs of states. It is also a commonplace that a quantum particle may be in a linear superposition of different position states and so may be 'in two places at once' when solutions of such functions are projected onto a Lorentzian manifold, with 'measurement' then reducing the state vector so that one alternative state vanishes to yield a unique position. It can be the case that the alternative was one of an infinite number of unoccupied position states in classical Cartesian coordinates and its vanishing, an infinite distance away, leaves that position state empty of any observable, with no trace of mass, charge or spin. But the distinction from standard QM introduced here is the proposal that such binary states are at the deepest level robust and that they live on nonlocal objects which, networked, would replace the classical manifold. In this case an alternative position state does not vanish, because a position which is not located at a vertex of the network has no meaning and all vertices are by definition paired. There is no notion of position which does not correspond to some implicit state of the network, meaning that a boundary condition analogous to that of a central field at infinity need not occur. Then, all quantum labels must be attached at vertices and the same conservative principle applies. Indeed, the general question of the origin of conservative forces and the peculiar aptness of Hamiltonian/Lagrangian functions in such a wide range of areas is arguably addressed more naturally in such a context than by assuming that an homogeneous central space-field approximation is valid everywhere.

viii.) This last issue, of the weight that nature seems to attach to such functions (most generally, the action function analogous to the classical Lagrangian), is of acknowledged fundamental interest but remains not wholly understood [19]. A connection between quantum mechanics and spacetime, *via* the relativistic invariance of the action functional as embodied in Noether's theorem [20], was achieved in Feynman's spacetime representation [21], but the deeper extension to quantum gravity has not been made. And one sees that this relates to the fact that *the origin of the Planck constant itself* is not really understood in present theory and remains a mysterious expedient with no underlying physicality. The ontology outlined here does address this issue directly (see *4.iii* below). Briefly, the locality condition of our construction (see *2.vii.* below) is embodied in the network rule that each end, *exclusively*, of every 'object' is connected by one object to each end of all other objects, so that the network only self-interacts *via* these fermionic ends of its object-elements. This means that the self-interaction associated with a conserved fermion number remains linear, or alternatively that the fermion number may be considered to change, but only subject to self-consistency requirements of a conserved total energy, in which case the self-interaction rate also remains linear. This linearity can therefore be said to underlie not only the linear non-interactivity of Bose-Einstein photon statistics but also the fundamental quantum condition itself, which becomes that of a network of scale-free Planck oscillators. This will be easiest to exhibit by showing how it fits with the canonical early history of quantum theory.

ix.) As is well known Planck applied his own quantised radiation law [22] to an internal atomic oscillator, preserving a radiation field with continuous energy density variations through an arbitrary volume. Einstein [23] applied the same law directly to the radiation field, again in an arbitrary volume. The classical Lorentz law for the incoherent statistical mixture of harmonic waves in some volume gave the mean square fluctuation of energy per wavelength as equal to the

Rayleigh-Jeans case, but the empirical black-body curve required the Wien distribution for short wavelengths. So Einstein rewrote the Lorentz law as a relation of a mean square fluctuation of a *number* of photons to the mean number of photons in some volume to account for the Wien part of the statistics, which leads to the Bose-Einstein distribution for an ideal quantum gas. But all these treatments assume a classical volume containing an infinite number of possible position states, either filled with waves or peppered with quanta. If the only actual approach to such a smooth volume is the linear network connecting some set of *pairs* of position states on its *surface* then the interior of the volume does not contain a continuous infinity of degrees of freedom. Thus a continuous wave theory will fail for the thermodynamic behaviour of enclosed monochromatic radiation of low energy density, whilst a particle (fermion gas) theory will fail as radiation density increases, because the interaction rate remains linear as the number of independent quanta passing through some region of the volume rises without limit. The entropy of this situation will evidently be the same as for non-interacting 'particles' reflected back and forth in the cavity, but the mean square fluctuation law given by Einstein as a statistic for an ideal photon gas can then be taken right back to the empirical black-body radiation law from which the Planck constant arose - i.e., it is a statistical law for radiation that is *always in equilibrium* in the sense that it is always 'enclosed' between pairs of fermionic observables (of which the radiation cavity is just a schematised case for large n), and each part of the total energy 'emitted and absorbed' satisfies the statistical independence of the elements of the Einstein fluctuation formula because of a linear self-interaction condition of the network. The photons 'in the cavity' are independent of one another because of a condition demanded for the locality of the network, which (we will argue) contains the Pauli exclusion principle as a special case and so demonstrates supersymmetry in the radiation cavity (see *2.v. et seq.*). This linear containment supplies the Einstein photon condition as a case of the Planck quantum condition by replacing both the continuous radiation field *and* its continuous space volume with a network of complex oscillators. The atomic Planck oscillator therefore does remain as a scale-specific case of this scale-free network, inasmuch as long-scale electromagnetic transitions between pairs of fermionic states of the network, mediated by its photon modes, are always associated with equivalent short-scale electric dipole transitions between pairs of electron orbitals. In all cases the notion of measurable position always coincides with a self-interaction involving a self-consistent state of the entire network manifest as some relative displacement or excitation of one of a pair of fermions. (See section *7.xx. et seq*. for a development of this argument. There it is shown that there should be observable cosmological consequences of this model of black body equilibrium.)

x.) Evidently, saying that there is no notion of position which does not correspond to some implicit state of the network is equivalent to saying that a 'measurement' is just a particular case of the general quantum transition process, as for example in a Bohmian ontology. But in the latter the Schrödinger wave function represents a continuously varying field acting on point-particles, where empty wave packets corresponding to alternative states that are unrealised in a particular measurement carry parts of the wave function away (as it were) until the 'inactive information' they contain is entirely degraded in the generality of other 'measurement' transitions [24]. The situation described in *vi.* - *viii.* above is constructively the same in the sense of its implication for the 'null measurement' paradox and the cat problem etc., but the wave function would *not* describe a nonlocally-varying potential of a continuous field in which (say) a photon wave packet might in principle spread to infinity without ever encountering an atom in a suitable condition to absorb it. The perennial problem with having concentric disturbances that spread though this stack of quantum fields pegged out over a metric manifold is: If the packet should eventually encounter such an atom, how does the indefinitely spread-out wave then get absorbed as a single quantum? (Note that this is every bit as problematic for gravitational radiation on the metric manifold as for light on the em field, so the stack isn't even soundly underpinned.) Standard QM has itself struggled with ontological implications of Eddington's [25] 'ray of luck' conundrum for decades, of course, and has conceded failure, by and large retreating to the default 'Copenhagen' epistemology of Bohr, Heisenberg *et al* rationalised by the probability-amplitude formalism introduced by Born [26]. But a Bohmian ontology brings this problem back into focus. The Bohmian answer to the criticism of Renninger [27] in relation to this point is to allow the atom to 'sweep in' the energy of the entire wave packet thanks to a nonlinear and nonlocal 'super-quantum potential'. Bohm's nonlocal quantum field thus *immitates* the existence of discrete bosonic quanta of a local field and effectively reifies the standard phenomenology. But in either model it remains the case that 'inactive' information states or uncollapsed quantum amplitudes can be imagined to disperse asymptotically at infinity. On the other hand, if all quantum labels must be attached to paired vertices in a network of nonlocal objects then there is a simple scale-free boundary condition: The only valid solutions of the wave function would live on this network of objects (of which there *may* be an indefinite number). It then makes no sense to think of a photon going nowhere, since a photon is constrained always to be a relation between two vertices. This principle of course *contains* the quantum condition of electromagnetic radiation deduced by Einstein [28], according to which the energy of one quantum of light goes directly to one electron so as to explain the photoelectric effect observed by Lenard [29], and it provides an ontological basis which imposes the Wheeler-Feynman [30] 'absorber theory' boundary condition (otherwise asserted by an extraneous prescription) and thereby illuminates the Cramer [31] transactional QM interpretation (see *Part 6*). In standard QM, and I believe in Cramer's transactional theory, it remains true despite field quantisation that radiation can be described as concentric spherical waves some of whose energy can remain unintercepted at infinity; but in our new ontology the correct (local) generalisation of the Einstein condition would be that the energies of *all* bosonic quanta go directly *from* one fermionic vertex *to* another. Two-valuedness of elementary local position means not merely that a fermion or a boson *can* be in two places once; it evidently carries the much stronger and more pregnant stipulation that *no supersymmetric combination of boson and fermion* can ever be in *less than two* (vertical) 'places' at once.

xi.) If this sounds strange, consider that a single-valuedness of the variable 'position' is demanded by a classical local vector field or manifold with a continuous infinity of degrees of freedom attached to a continuous infinity of coordinates in space. Such position states on a classical manifold have proved problematic for a traditional perturbative quantisation of gravity (neither standard QM nor any of the interpretations mentioned include gravity at all). Traditionally, attempts to quantise this manifold assume a discrete structure near the Planck scale and hope to recover GR as an approximation valid in a *large scale* classical limit so that an effective single-valuedness of spatial 'position' becomes *available* (even if not occupied with certainty) on length scales comparable to those of measurements in QED. Given this programme one can defend the received wisdom mentioned in *1.vi.* above - that the wave function tells us *all that can be known* about the system - from the objection that it doesn't include 'gravity', by saying that gravitational effects are either confined to fluctuations at the Planck scale or are small GR curvatures on very large scales - either way, a vanishingly small correction for all practical purposes. But this is circular: It is vanishing only in terms of a quantum field theory of gravitation where position becomes single-valued on a manifold with an effective continuous infinity of degrees of freedom, because then the force constant reflects a ratio of coupling strengths of fields which can be mapped onto one another with a point-to-point equivalence. The 'vanishing correction' argument assumes that departures from positional single-valuedness (i.e., as some radically altered topology) can only occur on length scales so small that they are smoothed away for any possible measurement. If this is fundamentally wrong because position is *generically* not single-valued (i.e. if the boundaries of scalar volume elements of quantised spacetime are not inevitably some approximation to single-valued point positions) then what is left out of account in the quantisation procedure might be a 'correction' so radical as to transform the procedure. Then one might conclude that the wave function gives an extremely accurate half-answer to a half-question, whereas the 'missing' context would transform the answer by addressing the *whole* question. If local position were only ever half of the total position specification of an elementary object, then it would never be possible for the wave function to give a complete prescription of any ensemble of point-electrons without also including all other possible point-electrons with which those in the ensemble might form nonlocal doublets. This is of course held to be true in a general way in standard QM, where a many-particle wave function involves the many position observables jointly, but the assumption there is that a function with the identical number of eigenstates can be extended to the set of all such systems (quantum cosmology) in a highly conservative linear extrapolation based on the hope that a quantised geometrical theory of gravity at large scales can remain a 'vanishing correction' somewhat aloof from a quantised theory of states at particle scales. On the other hand, the principle of two-valuedness of elementary position is *a priori* a scale-free principle, and leads to the idea that 'intrinsic spin' devolves from a generalised nonlocal spin symmetry which (this paper will argue) gets locally broken and for which the wave function requires an additional *hidden* momentum eigenstate. Therefore this very speculative possibility cannot be ruled out: That the *breaking* of a generalised nonlocal 'intrinsic spin' symmetry, or *superspin*, which respects a fundamental two-valuedness of 'particle' position, is equivalent to the *introduction* of a gravitational symmetry, so that a spectrum of (imaginary) angular momentum eigenvalues is hidden, in a manner without regard to scale, in the relativistic symmetries of spacetime.

xii.) The idea that a spin symmetry might be ontologically prior to the continuous coordinates of the metric manifold is not new, of course, and the view that the manifold in some sense 'hides' a superspin symmetry is perfectly conventional in the sense that the space of quantum spin supersymmetry is already taken as a superadded coordinate space attached to a point particle in 4-space. Physics has become at ease with augmented Cartesian coordinates. But the implication of recovering an intuitive ontology for *intrinsic superspin* might be more radical, as indicated above. As suggested, instead of augmenting the spacetime metric we might wish to allow the constraints of superspin symmetry to alter the radical function of 'a particle in 4-space', which would be equivalent to putting all possible spacetime position measurements into correspondence with elements of the quantum spinor field by identifying 'an electron' as a super-spacetime element defined by a pair of spinors. This would be moving so far from the notion of a quantum field theory formulated over a classical metric manifold that a system of electrons would start to look like an analogue of a loop quantum gravity weave [32] stretched to macro scales, with echoes of the Penrose spin-network programme [33] in which loop quantum gravity has its origins. But these likenesses are merely suggestive. It is at this stage entirely unclear how a field description of localisable, unitary 'elementary objects' passes in some appropriate limit to a combinatorial description in terms of nonlocal, *binary* 'elementary objects' whilst preserving most (but hopefully not all: *vide* the unrenormalised electron self-energy) of the results of integrating over a continuous manifold. Nevertheless it can be argued that the evidence for long-range nonlocal correlations in fermion and boson spin suggests some *rapprochement* along these lines in at least a restricted class of cases, and a little conjecture about the possibility of generalising from these correlations to other cases may at least do no harm. (Let me acknowledge again here that I am fully aware of how very speculative these suggestions are, but since speculation is the point of this essay I stop short of apology!)

xiii.) In broad principle this is a much more *conservative* position than might at first appear. The Copenhagen epistemology [34] declares the relation between observables to be unanalysable, a position which has sometimes been construed as positivistic, sometimes as epistemological. The correlated spin operators of a long-distance pair of EPR measurements, or an atomic wave function which is symmetrical in the two position coordinates of a spin-balanced pair of electron states, can be described as examples of scale-free elementary quantum systems 'without parts'. Once it is pointed out that the limit of the unanalysability in these cases occurs as two complementary or reciprocal states whose essence is a space- or time-like separation of two measurements, and when it is realised that the extreme case of a symmetrical two-electron wave function at the lower limit of scale finds epistemological equivalence going over into ontological identity (Leibnitzian indiscernibility), then a deep connection can be discerned between spin and displacement. It is then not such a difficult leap to derive this unanalysability of a pair of spinors from that of an underlying, non-local, object-like substrate rather than from the superposition of a quantum spinor field and a metrical field (classical or quantised). There is indeed a certain economy in this point of view. And if the Copenhagen interpretation of QM can be described as a scale-free epistemological relation of observables which does not include gravity, we could describe a successful formulation of the present point of view - should one ever emerge - as cousin to a Copenhagen interpretation which (implicitly) 'includes gravity'.

xiv.) The suggestion is that the partless element discovered in these correlations is an element not just of a restricted class of wavefunctions but can be generalised to a binary element of *all* pairs of electron states, of which certain classes are selected out by the spin correlations we have discussed as belonging to a restricted symmetry group. Now in the ordinary way a very limited loss of unanalysability due to parsing the general set of all spin-pairs into two classes (the correlated and the not) may not be thought too onerous - as long as the correlation can be treated as a rare and generally unnatural deviation from the randomised norm, to be dealt with separately. This assumes that the 'randomised norm' is effectively a flat background to the special cases of interest. But if each non-correlated pair breaks a general symmetry in a different way then this assumption fails and it is the background which contains a great deal of information, notwithstanding that the few rare 'deviations' in which that symmetry remains preserved exemplify *un*analysability. This 'figure/ground reversal' illuminates the fact that the unanalysability criterion of the Bohr system is a defining criterion of a non-relativistic model which doesn't give an account of intrinsic spin. It is as a result of 'simply' seeking to linearize[3] the relativistic relation $\Sigma p_r^{\,2} + m^2_{\,0}\, c^2 = E^2$, that Dirac [35] introduces new momentum components and four new 4-by-4 matrix operators in place of the 2-by-2 Pauli matrix for the fermion wave equation, giving rise to spin angular momentum and magnetic moment variables in the context of a properly Lorentz- invariant wave equation. Why does this procedure generate spin states 'like a rabbit out of a hat', as it has been described? We can express what happens by saying that imposing a local spacetime symmetry lifts a degeneracy in a basis state which takes on eigenvalues characterised as 'intrinsic spin'. In one sense this is 'obvious'. Spin angular momentum cannot have meaning in the absence of mass and space relations, and a magnetic moment has no meaning in the absence of magnetic field; spin is therefore co-emergent with the magnetic field relations which *are* space according to SR, and with the mass relations which generalise that space according to GR. Classically, therefore, one could ignore the idea of a degenerate spin eigenstate as simply unphysical. But this is not strictly permissible in QM. Although electron spin is never seen except as a positive non-zero eigenvalue, the formalism accords to it a zero value at which the eigenfunction does not vanish. (See *3.v. et seq.)* The issue of this paper then focuses down to the question: 'What *is* this quantum basis state that is *prior to* spacetime rotational symmetry but only expresses non-degenerately in terms of it?' And the interpretation suggested is that each electron spin *as measured arbitrarily in relation to any given other electron spin* is a non-degenerate state of an eigenfunction properly intrinsic to doublets. A degenerate 'superspin' eigenfunction would identify an EPR-correlated spin-singlet. The degeneracy is lifted generally in the spontaneous symmetry-breaking that gives rise to the Lorentzian spacetime relations embodied in the 'field' of electrodynamics, and so it is the *absence* of spin-degeneracy in the randomised background which hides what can thought of as a torque or restoring potential in the spacetime relations of electron pairs.

xv.) It was suggested that an ontological interpretation of a generalised superspin symmetry might even lead to an improved intelligibility for QM as a whole. At this point one anticipates the objection *a priori* that the edifice of QM is too tightly interlocked either to be substantially reinterpreted or extended without disturbing the extraordinary coexistence of local and nonlocal connections that it permits. An inherent randomisation accurately cancels out all opportunities for nonlocal signalling to preserve relativistic self-consistency. The interesting question of whether the present formulation of QM is the only form of the theory that could protect locality in this way was addressed by Popescu and Rohrlich [36] who proved that nonlocality and a no-signalling condition could indeed coexist even in a theory which assumed very strong entanglements. 'Supercorrelations' between the spin measurements of entangled particles in their model universe might be a weak

3 The Klein-Gordon equation being second order in *t* led to negative probabilities.

version of the superspin correlation posited here as the unbroken condition of a generalised spin symmetry. Of course it remains to be seen if, and exactly how, such a generalisation might be achieved. It is obvious that the most general symmetry group to which the spin-correlation group belongs, as a restricted set of a general spin symmetry (***s***), will also include the mass-energy (***m***) and the electroweak symmetries (***e***). These groups ideally will all imply one another in terms of the space-like nonlocal object substrate mentioned in *ix.)* and *x.)* above. Thus (***e***) will include the electromagnetic gauge which transforms the scalar (**s**) to vector potentials by bringing in a real time, such that $\{(\boldsymbol{s}) \Leftrightarrow (\boldsymbol{m}) \Leftrightarrow (\boldsymbol{e})\} \propto (\boldsymbol{g})$, where (***g***) is a gradient of vector potentials *equivalent* to the Einstein gravitational tensor. But it is evidently not possible that our generalisation could lead to a tensor field with potentials at all points of a continuous real space since we are attempting to include the symmetry (***g***) in the specification of our elementary object(s) without recourse to a classical metric manifold.

xvi.) The effect of demanding a metasymmetry in this way is to restrict dramatically the spacetime degrees of freedom to those made available by the substrate, in such a way that an approximation to a concentric wavefront of radiation in phase can generally occur only at *short* scales (or with induced coherence, or at horizons), becoming increasingly an imaginary wavefront of separate diverging elements at longer scales. 'Radiation from a source' becomes some set of definite radius vectors corresponding to a set of linear objects coordinate at the 'source' and so each quantum is constrained to correspond to a discrete 'history'. Visualised as a construction in geometrical optics it now becomes possible to trace quanta 'backwards' from their absorbers as smooth fronts converging on their foci. This construction is potentially helpful in understanding the logical structure of quantum theory. In particular it elucidates wave/particle complementarity and allows implications analogous to those of Feynman-Wheeler absorber theory and Cramer's transactional interpretation of QM to be discussed without reference to the degree of openness/closure of any cosmic spacetime geometry (*Part 6*). It is also the inverse of the large-scale averaging of small-scale divergences that is characteristic of the usual quantum formalism. Insofar as (***g***) and (***e***) in *1.xiv.* above stand for the symmetries of, respectively, general and special relativity, this inversion has interesting implications for a quantum theory of gravity. In particular, the dramatic restriction of the degrees of spacetime freedom to those paths actually congruent (in terms of some map correspondence to be discovered) with the nonlocal object-like substrate suggests the possibility that the constraints imposed on a necessary reformulation of the QED quantum condition *may produce automatically the quantum condition* of a future non-perturbative, non-field theory of gravity. Interestingly, the discrete form of the substrate seems to suggest that, if it should prove possible to recover some duality with GR, this duality would *not* extend to gravitational wave radiation as predicted by GR. But leaving these remote speculations to one side for the time being, let us return to the question of electron spin.

2. Ontological Basis of a Generalised Superspin Symmetry

i.) It is evident from *1. i.)* and *1. ii.)* above that an electron conceived as a local object is unable to support spin as an intrinsic period in any degrees of spacetime freedom available to it. Moreover the two-valued quantisation of this spin is classically unphysical as a gyroscopic rotation, being more like a polarisation, although that description is usually reserved for light-speed photons. So the orbital angular momentum correction demanded originally by the Paschen-Back effect in the Zeeman components of the yellow sodium line, by the Einstein-de Haas anomaly, and so on, cannot be accounted for by treating an electron as a particle with classical magnetic moment and angular momentum. Intrinsic spin is not even a properly localisable quantum variable either, since it becomes well-defined only in ensemble measurements. It is possible to conclude, then, that an electron may not 'have' an intrinsic property called spin, and this is a rational corollary of the fact that there is no evidence of *local* internal electron structure at each point where one half-unit of 'spin' is measured. But might there be a '*nonlocal* internal structure' part-revealed at each of *two* points (let us call them nodes) where spin is measured? This would be equivalent to saying that a 'hidden variable' responsible for determining a binary quantity called spin is interior to 'an electron' whose interiority is redefined as a *nonlocal object*. (The discussion is of course abstract and this static 'object' gives little insight as yet into the form of any dynamical treatment.)

ii.) In this way we are attempting to build a nonlocal quantum object whose nature is always to interact at *two* points or nodes characterised by reciprocal spin vectors, which vectors enjoy a general transpositional symmetry. We will look more closely at this nonlocal object in a moment; but since we do not see its transpositional symmetry respected except in special cases (EPR-type correlations), the assumption would be that the metasymmetry is in general broken by interaction (meaning almost always, at the 'classical level') but that it persists in atomic Pauli spin pairs and may in special conditions be preserved over long distances in EPR pairs. A second assumption would have to be that although the metasymmetry is broken at arbitrary scales for the majority of these nonlocal objects (conventionally-speaking, these 'pairs of electrons') there will be something in the theory that mediates the hidden (broken) superspin symmetry. It is natural to suggest that the something which hides the broken spin or polarisation symmetry is the photon, which would make the carrier of superspin symmetry identical (or at least congruent) with that of charge. Briefly, the suggestion offered in *Part 4* is that the superspin symmetry would be hidden in an imaginary 'super-rotation' of the plane of polarisation of a (linear polarised) photon. Although the photon would carry superspin it would not 'see' it, *due precisely to its super-rotation*. It would 'see' the restored superspin symmetry normalised (in null proper time) to that of a spin-zero scalar 'particle'; but an imaginary *torsion* in this particle (our nonlocal elementary object), which may *a priori* be any arbitrary fraction of phase, is preserved as a scalar potential in the limit of an electromagnetic vector field which is emergent in the breaking of superspin symmetry (See *4. iii.* below). This could be thought of as analogous to a *quantum 'Faraday effect'*, where instead of a magnetic field rotating the polarisation plane (*continuously* in Cartesian coordinates) of classical light waves traversing a dense medium, we have a 'superspin field' which is the zero sum of imaginary *discontinuous* polarisation-rotations of individual almost-monochromatic light quanta whose angles are normally regarded as constant under Lorentzian translations in vacuum (as found in Malus' experiment for classical waves, where the plane of linear polarisation is independent of the separation of the reflecting plates). One might then say that the fundamental quantum unit of boson spin, $h/2\pi$, has a function crudely analogous to Verdet's constant in the theory of magnetic rotation, so that

$$\theta/\lambda = (h/2\pi)Hl \qquad (2.1)$$

where wavelength λ, pathlength l, and 'field strength' H are all normalised to unity and where θ is like the *specific rotation* of the vacuum. (A connection to spacetime theory can be made by describing each quantised 'lurch' in the 3-space of paired spin orientations as a torsional stress in a properly-null geodesic interval whose projection on 4-space becomes a line element of the Einstein curvature tensor. Again, see *4.iii. et seq.* for development of these issues.)

iii.) In these very general heuristic terms the picture that emerges makes sense of the spin-balanced, symmetric, two-electron atomic wavefunction, and of the related EPR-type pseudobosonic entangled pairs found in superconductors, where Pauli exclusion and Coulomb repulsion respectively are similarly suppressed.[4] Indeed atomic electron pairs are more than casually similar to inertia-free BCS pairs in a cold superconductor. The electromagnetic gauge symmetry can be regarded as broken in a superconductor, electrons losing inertia and photons acquiring it. The implication is that the electromagnetic gauge symmetry *is reasserted only where the general superspin symmetry is broken,* and that it is *in the emergence of the electromagnetic gauge symmetry that electron inertial mass also appears,* in a way which can be regarded as an incorporation of the spin-zero scalar particle mentioned in *2.ii.* above. (In this analogue of a Higgs mechanism a Goldstone boson in effect generates inertia through the radial *form* of the spin-zero scalar 'field' mentioned in *1.xvi.,* and so 'donates mass' directly to electron pairs through their photon coupling. Since this is an emergent property of the electrodynamical self-interaction of the 'field'

4 Kiesel, Renz and Hasselbach [37] have recently restaged the classic Hanbury Brown -Twiss photon correlation experiment using free electrons and find that anticorrelations are observed as predicted for antisymmetric fermion wavefunctions, i.e. these free electrons obey Pauli exclusion. Samuelsson and Buttiker [38] have recently proposed that superconducting electron *pairs* injected via a quantum dot into a pair of normal conductors would behave differently. Their calculations lead them to expect that as pairs split to enter the two conductors they will give rise to positive current correlations typical of Bose-Einstein behaviour.

there would be no intermediate massive Higgs boson in this theory. See *4.iii.*)

iv.) Immediately the question occurs: 'Given that mass is held to be a fundamental property of a particle at rest and is a measure of its inertial coupling to some coordinate point of space, what would it mean to assert that our binary electron had a rest mass at *two* points of space?' It would appear to mean as much as to say that it had half a quantum unit of spin at two points of space, except that mass is conventionally a scalar lacking even the rudimentary 'up' or 'down' vector states of spin. But notice that there *is* a mass vector, whenever a *system* of particles is considered. In this respect mass, just like spin, acquires a well-defined vector during a participatory 'measurement'. Both are context-dependent. The mass vector is a directed 'force' which appears as an acceleration ('inertia', or 'weight') in the relativistic symmetry; but the local particle description *reduces an energy-momentum four-vector to a scalar mass point for theoretical purposes*, and thereafter spacetime geometry has to be substituted in order to recover mass as a directed quantity. Note that a pair of electron masses represents a constant action in any relativistic transformation, which can be represented perfectly consistently in terms of the locally-conservative Lagrangian of one homologous nonlocal object (see *2.v.* below). In fact every un-ionised atom in the universe heavier than helium is a demonstration that the 'natural' minimum-energy condition for a pair of spin-balanced charges is a nonlocal state in which the function of a metric to define an ontological separation of points in space loses precise significance.

v.) But what are we to make of a fundamental nonlocal object as an element of a theory that has to give local answers? A local theory must be Lorentz invariant under transformation from frame to frame, but Lorentz invariance does not preclude 'absolutes' of which it can give no account. For example it does not preclude the existence of a preferred frame such as may be related to a hyperplane of constant time (or indeed an 'ether'). In fact the Lorentz group rotates around precisely such a frame defined at *c*, which is why special relativity demands that any elementary object *must* be nonlocal: Lorentz-invariant systems alone may be local, and a Lorentz-invariant system cannot be an elementary object. A classical particle or a quantum point particle are both *non*local elementary objects, the latter being simply an extremal form of classical rigidity retained in the limit of SR. But although SR excludes extended classical rigidity it does not exclude extended nonlocal objects, and therefore does not limit an elementary object to a limit of scale, provided only that the elementary object is Lorentz-invariant *insofar as it may be 'observed' with photons* (or more generally, insofar as it is an interaction within the larger symmetry group of QED which includes spin). In other words SR allows nonlocal objects that mechanically transform with, or 'underneath', their local labels (i.e., an ether). Whether such a covariant nonlocal object has a useful theoretical function is a different issue; but in principle SR does not require its absence. Therefore the reason why point particles are acceptable (classically speaking) as a nonlocal element is not primarily that they don't transform, although they don't, but is for the subtler related reason that, being zero-dimensional, they will always *interact* zero-dimensionally. But one-dimensional objects may be constrained to do this too. This then is the general condition that nonlocal elements cannot violate consistently under SR, *irrespective of scale*: They must only interact with one another zero-dimensionally.

vi.) We can also show that applying this principle to one-dimensional elements irrespective of scale is the same as giving a generalisation of the Pauli exclusion principle, which, as expressed in standard QM, would now be retained only as an extremal case for short scales. These short scales assume a disproportionate significance in standard QM (we would now say) because of the focus on small local differences between terminal values of nonlocal objects which in fact have *arbitrary* scales.(As suggested in *1.ix.* the same focus led to a failure to generalise the atomic Planck oscillator and thus eventually to the conceptual ambiguity of the quantum field.) Thus the spin-balanced symmetric wave function of a Pauli pair with the same orbital quantum number describes the unbroken spin-symmetry in an atom *A* between two nodes *A′ (up)* and *A″ (down)* which are also nodes ('ends') of *n* other nonlocal objects of arbitrary scale. Considering any two of these *n* other objects we can assign additional quantum numbers to them describing their scales and their relative polar coordinates as radius vectors. If these numbers are the same (within the brackets of quantum uncertainty) then we will find that their opposite terminal nodes will also form an equivalent Pauli pair *B′* and *B″* on some coordinate point we might designate atom *B*. Then *[A'(up)↔B'(down)]* and *[A"(down)↔B"(up)]* form two antiparallel complements of spin vectors, and the characteristic scale of Pauli exclusion which we take to define atomic scale is seen to be just the lower limit of a *dipole* (see also *3.vi* below) which operates on any scale. Two binary objects like *A'↔x′* or *A'↔y′* may share *one* common node, but *evidently they are unable to share two common nodes without being the same object,* which is to state in more vivid terms the same exclusivity required by the condition that our two nonlocal objects *may only interact (i.e. be in the same positional state) at their ends.* Evidently it is this condition which *imposes* locality on a system of such objects, and it may be legitimate to go so far as to say that it is our binary construction which, by thus requiring a system of emergent angular relations, is the *origin* of the SR symmetry group as the invariance group for observables. (See *Part 5*.)

vii.) For our purposes, then, an elementary nonlocal object whose observable spin-dynamical states exist only at its ends does not conflict with SR because it behaves as a 1-space and interactions are linear (see *1.ix.)*. Similarly, some string theories with 'open' strings work by carrying their quantum labeling on the free ends, so that the strings only recognise one another end-on. Notice that this is an interesting scale-model of the nonlocal binary objects we are considering, which likewise would carry their quantum numbers on their ends. In general, string theories using extended elementary objects can be kept local because interactions only occur at a 'point', even for closed strings. Of course these theories are formulated down at the Planck scale, but the scale itself becomes significant in these theories for quite other reasons that have nothing to do with relativistic invariance. Within the limits of our heuristic model as it appears so far, we can make our nonlocal objects on any scale and because SR is only concerned with the Lorentz-invariance of these ends it is indifferent to nonlocal correlations of the states that are not Lorentz-invariant. It does not have anything to say about a space-like relation of these two states provided that they are consistently labelled. It simply doesn't explain this consistency. Superspin symmetry would be what absolves SR from *having* to explain such correlations, which it would have to do (self-destructively) if such correlations were the general rule. One could say that superspin *protects* SR symmetry from 'correlation pathology' by carrying the broken symmetry away invisibly (analogously to the way that the neutrino carries away the energy and angular momentum in electroweak interactions to protect conservation symmetries in beta decay.)

viii.) This is equivalent to a no-signalling condition for EPR pairs, but although spin entanglements are usually considered as the type of what Shimony [39] called 'passion at a distance' it is a case of a general principle that is robust for all quantum labels, without ever becoming pathological action-at-a-distance. Action-at-a-distance becomes a paradox from the point of view of SR if instantaneous actions are observable within SR (i.e. by local observers). Since the finite value of c in SR denies the possibility of instantaneous measurement for all observers ruled by SR no such paradox can arise within SR. This does not deny that in a preferred frame, such as that of c, all actions are in fact instantaneous. Again we can see that it is our 'end-on interactions only' locality condition, expressing a broken superspin symmetry as Lorentzian displacements, which protects SR from paradox. Or alternatively, c protects our binary locality condition from infinitesimal collapse; or h is the non-zero constant of superspin symmetry which prevents c being an infinite constant of Lorentzian symmetry. In general, what prevents the snake swallowing itself by its own tail is that *any* set of states found as measurements of *end points* by an observer moving $< c$ will be by definition locally Lorentz invariant under SR without regard to their nonlocal object-connection, which is simply irrelevant as it does not contain a real time - just as a point particle does not contain a time, or as an ether does not contain a real time. However a point particle does not contain anything else, either, and is therefore so uninteresting as to be useless; whilst an ether contains altogether too much and destroys the clarity of our binary locality condition. In other words, as long as there exists a 'preferred frame' in which the null connection state of zero time appears, a linear object may be both sufficiently elementary *and* sufficiently interesting by virtue of carrying a pair of labels at *A* and *B*, which must be symmetrical under a *nonlocal* longitudinal rotation such that |*AB*| may be set effectively at zero within SR. This condition is represented by the photon speed *c*. It would be problematic if such rotation produced an asymmetry of mass or charge under vector transformation; but rotation within |*AB*| of electron mass and electron charge produce *no* local change of state as long as they are scalar magnitudes which for the purposes of SR are wholely specified locally/relativistically and the total energy of the Hamiltonian remains constant. Again SR does not *explain* mass and charge; but again it is not required to. The causal topology for a network of such pairs might in principle look very interesting in the 'preferred frame' in which the broken spin symmetry is repaired (which is the imaginary frame in which the photon super-polarisation would appear); but since the space-like null hyperplane of *c* can only be objectified by a wholly imaginary observer there is no deterministic local history involved and therefore no causal conflict in any particular case.

ix.) Problems with nonlocal objects only appear in local *field* theories which have to be defined at all points of a continuous space, when a number of those points are required to be occupied simultaneously by the nonlocal object. Our nonlocal objects are not going to be part of any such conventional field theory because they pre-empt the notion of a continuous background space. (One might say that they interpolate *between* those "points" rather than occupying them.) There are traditionally relativistic difficulties with extended fundamental objects in conventional Faraday-type field theories because events at different points on the object which are spacelike-situated might interfere with one another and violate causality. As mentioned, this difficulty is elided in superstring field theory by ensuring that when the string loops interact they only ever do so at a point, so that the spacelike-separated points do not disturb one another. (Having ensured that photon vibrations, for example, will not propagate down the string faster than light. This is from a string theory point of view just the same as decreeing a global locality condition for the spacetime in which the strings move, whereas in our proposal there will be no such classical manifold and the condition has to arise from primitive relations of observables.) The extended objects suggested here would differ in that they do not ever *not* interact, in fact they interact exhaustively; but they too only interact at a point (or two points, one at either 'end') and indeed they promise to define the *meaning* of a 'point' by their interactions. (Taken in the cosmic limit our nonlocal object plurally *becomes* space.) This may be another extravagant feature and problematic in terms of general relativity; but it may also be regarded as desirable that a continuous background space should be avoided if possible along with the potential problems of a nonlocal field theory.

x.) But, so far, so good (?): We have a fermionic one-space object with a two-valued *nonlocal* spin symmetry which appears mediated, when torsionally broken, by the gauge boson of a resulting *local* symmetry. The torsional breaking of EPR-type spin symmetry appears, arbitrarily with respect to the "up/down" spin vectors of the two fermionic "ends" of our object, as the imaginary rotation of the plane of polarization of an individual photon. We have yet to consider the case of an ensemble of these objects, but on general grounds we can see no reason not to expect that the manifest local symmetry group will remain the Lorentz group of electrodynamics, within which the broken generalised spin symmetry is carried as a hidden quantum variable, the imaginary rotation of the photon polarization. Insofar as polarisation defines space dimension, is it possible that introducing an imaginary angular momentum variable in some complex reformulation of SR might reproduce the tensor components of GR from super-rotations of the photon coordinate frame, as suggested in *2.ii.*? This is of course no more than a pious hope; but that it is a hope at all can be taken to justify our decision to find a rationalisation of spin without resorting to the augmented coordinates of conventional supersymmetry. The reason for this is that the Lorentz transformations - both as formalised by Lorentz and as reinterpreted by Einstein - are historically and logically prior to their expression as rotations on the Minkowski [40] spacetime manifold. This geometrical representation was a rite of passage for a three-year-old SR and was subsequently reified by Einstein in the curvilinear space coordinates of the general theory. But this metrical continuity is in fact, *like standard QM,* a functional procedure, albeit more intuitive, derived from discrete observables which are primary. Hence the reason that attempts to quantise the manifold retrospectively have created legendary difficulty may be that they have attempted to quantise a procedure, not the primary actuality. As pointed out by Consoli and Siringo [41] GR can be considered an elegant device for calculating weak-field corrections to space and time measurements inside some some *other* theory to which the Equivalence Principle must be built in. GR expresses the experimentally-validated EP, but lacking an inevitable Machian form it does not *produce it*, so that tests of GR which only verify the EP and SR, neither of which depend directly on the GR tensor, are not necessarily evidence that the GR metric tensor formalism is fundamental. If so then an ontological interpretation of 'intrinsic spin' which eschews both the metric manifold and its still-further augmentation by abstract supersymmetric coordinates is at least not absurd on that account. An ontology of spin may not (yet) be a theory of gravity; but then GR is not a theory of quantum spin either, and there is no very obvious reason to expect that it ever would be. On the other hand a model of space distance which gives exactly the same metrical formulae as the non-Euclidean differential invariance of GR *can* be derived from an 'old fashioned' algebraic invariance suited to just such a construction of scale-free linear objects as I am suggesting here might rationalise 'intrinsic' spin (see section *6.ix. et seq.*).

3. Epistemology & Ontology of Spin Measurement

i.) The starting point for these speculations was the evidence that electron 'intrinsic spin' cannot refer to a gyroscopic rotation. Indeed it can be shown that, considered as particles, even the electron 'orbital' momenta are not classically 3-rotational as a class, because *s*-states would be straight lines through the nucleus. QM at this point retreats from all mechanical models. But the interpretation in terms of extended nonlocal objects broached here appears, so far, to be justified to at least some degree by the intuitive order it is capable of bringing to otherwise perplexing quantities. However, for such objects to be taken seriously they would have to lead to some clear explanation of exactly *why* the process of 'correcting' the electron orbital angular momentum by means of adding spin vectors to explain the spectroscopic fine structure [42] 'works' numerically. Pragmatically, the meaning of the spin component of the total angular momentum is a doubling of each of the atomic energy eigenstates into pairs of spectroscopic absorption lines at closely-spaced frequencies. How is it that these levels can be labelled symbolically as contributions from the 'up' and 'down' spin vectors of differently orientated electrons, although in QM electrons have no orientation marks on their surfaces - and indeed, no surfaces? If the spectroscopic fine structure is indeed related to classical 'angular momentum' then the implication of QM is that electron spin will have to be allowed to reinterpret the meaning of angular momentum, rather than *vice versa*. Therefore 'intrinsic spin' ceases to look like a minor correction, and we are led to expect that angular momentum *in general* ought to be understood in terms of some transform of the binary linear elements we have surmised.

ii.) Visualisation seems to me to be quite important here. It is an obvious and trivial point, but when thinking about absorption spectra one needs to remember not to confuse the abstract statistics of a system of 'radiation and particles' with the imagined concrete structure of an atom. The frequencies of the spectral lines represent not a series of absolute atomic micro-states somehow 'photographed' by light waves, but rather they are cross-sections through a dynamical map, sections through *a series of contours of gauge-equipotential difference* which exist as scale-free *relations* between what we characterise as a system of emitters and a system of absorbers. (This can be intuitively pictured as something like the energy levels in the band theory of solids.) They are of course not static pictures of states but dynamical shadows of interactions, countless photon tracks comprising sheaves of null trajectories between spatially remote intersections which we call electrons at atoms A and B. One level is a state connecting A' and B', the next 'higher' level connects A'' and B'', and so on. Both A and B generally stand for some large ensemble of atomic intersections, and the series of absorption lines is a statistical summation of activity taking place across these several bundled strata of gauge-equipotential difference, generally without regard to distance. Historically, classically, and reductively, one sought to explain these equipotential contours by associating them causally to potentials in isolated Keplerian structures of orbiting atomic particles, and, although this mechanical model has long since failed, the old programme of causal reduction largely remains in place. Thus today the emission/absorption energy levels still 'live' on redefined local particle-states, connected by exchanges of confined wave-packets; although 'everyone knows' that the primitive ballistic connotations of this sort of exchange should not be taken seriously.

iii.) It is possible to locate an electron energy level on a coordinate point in some phase space of very high dimension where this 'point' object has the same dimensionless nonlocal function as a null Cartesian point; but this space is not 4-space. What we want for an ontology that makes *intuitive* contact with the sensory world of discrete-objects-at-discrete-places is to be able to show how to contract a series of contours of equipotential difference down to a set of points in 4-space by some projection that doesn't leave classical spacetime (this is not because of any affection for the classical manifold, but to preserve Lorentz-invariant relations between *physically countable* observers/observables). So we have to see pairs of spatially remote states in some imaginary null projection. The only physical projection we know that *does* send a dimensionless point to its linear dual in 4-space and *vice versa* in this way is the relativistic projection whose fulcrum is the speed of light, and by happy 'coincidence' this gives us the photon's-eye view of a transformation that maps an excitation of a point state 'in' an atom to a positive time interval between *two* remote point charges in atoms anywhere in the universe. But this projection also threatens to give us, as a neat mathematical package, the entire classical spacetime manifold. In this way we find ourselves torn between the space-holists and the particle-reductionists, which is a good moment to remind ourselves of the manifesto of our linear 'third way'.

iv.) In fact this projection maps our two-valued nonlocal objects not just from points to lines but from points to lines *and* from lines to sheets. Leaving spin aside for a moment, one dimension of the sheet expands on the null signal line of a photon tracing the equipotential contour, the other appears as a sideways displacement of that contour at the head of the relativistic worldlines of two electrons. So the displacement of the equipotential contour, proportionally to the real time interval associated to the null signal line by a given observer, traces a two-dimensional world sheet which preserves the action. From this sheet it is then possible, by a reverse projection, to recover the idea of a downward electric dipole transition between a pair of atomic energy levels and a corresponding upward transition between a pair of spatially remote atomic energy levels. Which is the primary map projection? The particles? Or the sheet? And does it matter? Phenomenologically, no; but ontologically, it does matter. If we take the particle projection as primary then we can represent the orbitals (after a fashion) but not the intrinsic spin. If we say the sheet is primary then we have to represent particle trajectories by matching the edges of curved spacetime sheets made out of some unbounded prior geometry that is ontologically troublesome. What after all is the meaning of a prior non-Euclidean geometry, given that spacetime geometry has to be, if it is not a relation of nothing, a relation of observables? It is quite as hard to understand an *a*relational geometry as primary as it is to understand the antithetical null element of such a geometry, the geometrical point, as primary. Geometrical points can't be rationally constructed into anything; unbounded geometrical space cannot be rationally *de*constructed into anything. An ontology has to be built on measurable properties of observables, and rational measurable properties are inherently relational. Therefore, as argued in *2.viii* above, the elements of our ontology must be: a) simple, yet not so simple as to be uncountable; b) constructable into, or deconstructable from, a geometry of finite relations; c) local-relational *and* nonlocal-elementary. Which leads to the conclusion that our choice of the complex 1-space element is, according to the porridge principle, just right.

v.) Now as we saw (paragraph *1.ii)* the quantum spin state is a state which emerges in a participatory 'measurement' context involving the collective parameters of a *system* of 'particles'. In terms of the standard QM phenomenology this is simply mysterious - a 'given' of the wave function. This might be easier to understand if one could just say that spin is a phenomenon which appears in ensembles. Why, after all, should not new collective properties be emergent? And why should not an electron decide to acquire a spin according to spin 'instructions' derived from its neighbours? But this is not what QM says, as was pointed out earlier. It says that there is an increase in the space of quantum mechanical states for an electron, which doubles the number of energy eigenstates, even though the difference between the paired eigenvalues might be zero. It isn't zero, because the eigenvalue equation is said to be 'perturbed' by the presence of a magnetic field which lifts the degeneracy in the angular momentum quantum number to split the energy level into a group of orbital sublevels and spin sub-sublevels. But this perturbation does not alter the eigenfunctions. The quantum state space includes the spin eigenstates, in principle, whether there is perturbation or not. So spin is 'intrinsic spin' in this precise sense: that the *single*-electron wave function contains a spin state which is as 'actual' as any other quantum variable but is simply not well-defined. Definition is context-dependent, and the unmeasured spin state is poorly-defined; but not in the sense that it has one vague state, rather in the sense that it has a very large number of perfectly definite states each of a certain *probability*. We can express this by saying that the unmeasured electron spin state contains a huge quantity of statistical information. But the sense in which a point particle may be said to contain *any* quantity of information is unclear. It may be said that the information resides in the measurement field, but the wave function of this field itself has no clear physical interpretation in QM. As pointed out in *1.ii.* the number of spin terms for any many-electron system multiplies the dimension of the state space at an alarming rate, and again it is not clear physically how this abstract dimensionality relates to the wave function of the measurement field.

vi.) One possible advantage of the ontology under consideration here is that it allows an indefinite number of probable spin states to live each in its own *actual* complex space. Consider a set of our nonlocal objects coordinate at an origin, where we wish to specify a state of spin. The situation is as mentioned in *2.vi,* where it was pointed out that two binary objects like $|Ax|$ or $|Ay|$ are unable to share *two* common nodes, one at A and another at x *or* y, simultaneously without being *the same* object. This is our generalisation of Pauli exclusion to a *dipole* (which is also implicit in the locality condition), according to which they may however share *one* common node at A since their positional two-valuedness gives them a discernable nonidentity as different radius vectors terminating at different nodes x and y. Evidently the 'exclusion principle' is a special case of this dipole which has an opposite form as an *in*clusion principle, since we can give no reason *a priori* why an indefinite number of nonlocal objects should not share the node at A. Indeed our theory requires that the largest possible number of any set of N objects will always do so (remembering that the construction is that *each end* of every object is connected *by* one object to each end of *all other* objects). This number is $(2N)^{1/2}-1$, which interestingly is an integer only for certain values of N and in this manner offers a simple model of context-dependency in *atomic shell structure* (see *3.ix.-xi.* below). But in general for very large N we can see that because each of these objects has (according to our hypothesised general spin-correlation symmetry) at any imaginary 'instant' a reciprocal spin state specified somewhere else, then we have on the order of $N^{1/2}$ potential answers to the question: 'What is the spin state at A?' from which a unique result has to arise in response to some particular measurement. We have here the idea of a measurement operating to reduce a superposition of states (see *vii*. below) which is causal, and intuitive, yet *not* classically deterministic. Crucially, it is not classically deterministic - i.e., it cannot be predicted from knowable Lorentz-invariant positions and momenta - *for an intuitable reason*. In other words, it is a 'hidden variable' theory of quantum spin states in general.

vii.) The crucial feature of this construction is that the nonlocal spin-correlation symmetry which in principle *would have* allowed us to predict a resultant of this superposition of spins at A is broken by the local electromagnetic gauge symmetry. Thus, in principle, each spin state is fully cosmically determinate, in the sense that the outcomes of all 'instantaneous' superpositions (in some unit time), each of $N^{1/2}$ spin states, are cosmically self-consistent; but without applying a theoretical torque against the hidden photon superspin to recover this broken general symmetry there is no way to 'see' the correlations that are latent among apparently arbitrary measurements of 'ups' and 'downs'. Each of $N^{1/2}$ outcomes is therefore found to be a probabilistic detail of a merely statistically-deterministic classical state for a system of N objects. (One important metaphysical point should be mentioned in passing here, though it is too large to go into: Of course locality constraints mean that this information is never available locally, even in principle, which negates both prediction and nonlocal signalling. So although the global state is determin*ate* - i.e. causal - it is *not* classically determin*istic* - i.e. predictable. This is an important distinction. Only emergent mesoscale ensembles will have deterministic histories.)

viii.) It is fair to claim that the naturalness of our construction is here revealed in its aptness to the curious and seemingly arbitrary procedure for spin calculation in standard QM. In that procedure the probable spin of a particle is found as the complex linear superposition of some set of spin vectors in Hilbert space, which can be graphically represented as a set of radius vectors on the Riemann sphere. For simple spin-half electrons the projection gives a single radius vector as the resultant of a combination of 'up' and 'down', indicating a real orientation with respect to the local magnetic field. As Penrose [43] points out, this mimics classicality. But for massive compound fermions of higher spin N the spin state will be something like N different complex superpositions each of N orthogonal states, and the macroscopic spin *does not* emerge from a statistical averaging of random quantised spins at 'the classical level'; instead what happens is that a 'measurement' transition causes the spin state to *jump* to one of many values, thereby *recovering* a simple spin-half 'classicality' that had become lost in the higher-order quantum system! The spin that emerges is in general not like the resultant of all the radius vectors on the Riemann sphere; they only yield relative probabilities. The implication is that no matter how large a compound particle gets - even the size of a snooker ball, say - without this reduction of the quantum spin state vector its angular momentum will *never* go over into a classical state by cumulative averaging in the way that one might imagine by analogy with statistical gas laws.

ix.) This is a typically puzzling example of the measurement problem for quantum particles. But if we consider, instead of an ensemble of particles, a fairly large system of N nonlocal binary objects (in an imaginary 3-space for the purposes of visualisation; their 4-space projections become analogous to 4-vectors) then the number N of objects is related to the number N' of nodes like $N = N'(N' - 1)/2$, which is recognisably just the number of terms required to specify a two-electron wave function in a system of N possible position states. In general it is the number of unordered pairs of position states in the system, where a 'position state' is equivalently a network vertex, or node. For large N the number of nodes approaches $N' = (2N)^{1/2}$, or just $\sqrt{N}$ in the limit ∞, and the set of objects is characterised by $(2N)^{1/2}$ vertices, each the origin of approximately $N/(2N)^{1/2}$ radius vectors in polar coordinates, so that when N is normalised to unity in order to treat a system with a zero vector sum of linear momenta as a single object with a total angular momentum, this normalizing factor $1/\sqrt{2}$ will enter in. But for small N each nodal 'position state' or vertex (like A in

3.vi. above) represents a potential measurement of electron spin, where the spin state will be some superposition of the (N' - 1) different spin states associated with the set of (N' - 1) radius vectors terminating there.

x.) Atoms may be approximately objectified in this way but their 'internal' structures show exactly why objectification is never truly context-independent. To recap some well-known background: The old mechanical ontology of shells and orbitals appears to allow a degree of objectification of different substructures, with the K shell filling, then the L shell, and so on, with each new electron assigned to an objective state within its shell independently of those to follow. The Pauli [44] exclusion principle controls this assembly process by giving the number of electrons of principal quantum number n according to

$$N_n + \sum_{0}^{n-1} 2(2l + 1) = 2n^2$$

Schrodinger offered a new ontology that made Pauli's 'policing' of quantum states seem less unnatural, producing discrete 'orbital' angular momenta by mixing standing waves of different phase and amplitudes. In wave mechanics doubling the number of states to allow for spin means that the wave function may be symmetric in certain pairs of electrons, i.e. they may be interchanged without altering the function, which introduces questions about the exquisite distinction between identity and indiscernability and requires a many-particle treatment in which all particle states evolve simultaneously. This many-particle wave function has no location in 4-space and the unitarity of its evolution in phase space brings in the awkward issue of reduction. It is another successful phenomenological theory, but again one which seems to fail in its goal of representing atomic phenomena as objective.

xi.) The possibility of capturing useful features of these theories in a network ontology can be illustrated by reducing the structure problem to connections. Thus, in any very large ensemble of N nonlocal linear objects networked according to our simple rule (*each end of every 'object' is connected by one object to each end of all other objects)* the state found at any vertex O will be some superposition of the states associated with the set of $[(2N)^{1/2}-1]$ radius vectors or 'objects' having an origin at O. But attention has already been drawn (*3.vi.*) to the fact that this formula is only asymptotically accurate in the limit $N \to \infty$ and does not in general have natural integer solutions. So why is it interesting? Because the natural numbers which it does produce belong to the sequence of values of N beginning 2, 8, 18, 32, 50 . . . which we recognise as the number of electrons in completed K, L, M, N, O . . . atomic shells. Now what does this mean? What we have done is treated the problem as though for a single 'atom' whose electron occupancy approaches infinity. But the interesting thing is that if we enclose any small region of this network where N is small we can then count a finite number of nodes (points of local measurement where null photon lines terminate) and if we calculate the maximum internal connectivity of this set of nodes the above sequence of values corresponding to interesting electronic structure *never emerges*. As will be shown momentarily, solutions which have physicality are therefore inevitably dynamical solutions not statical solutions, because there is no 'atomic architecture' except as enacted in the interactivity of the *class* of structures called atoms. Thus these numbers are evidence that the gauge-equipotential epistemology of *3.ii.* does reflect a primary ontology.

xii.) The sense in which the progression from 2 to 8, and from 8 to 18 and so on, 'builds' successive shells is clear: it is entirely a phenomenological ordering, not a physical order of priority. The ontological order of the physical structure expressed in these magic numbers is an interconnectivity that exists across *all* shells, so that the operation of the rule for the K shell occupancy has no meaning in a universe solely of K shells. This is because we are not asking that some units assemble themselves into a structure under instructions from their internal programming; neither are we expecting them to enact the instructions contained in some 'field' or invoking a Platonic law. Crudely speaking, the numerical structure is just an inevitable outcome of the way some collection of rods is obliged to stick together. This atomic holism might be called a weak, local, context-dependency. But it in turn must be assumed to operate under a stronger, global, context-dependency that arises from the global self-consistency condition of the network. This is implied by the hypothesis, and as intimated above there is also the rather curious and subtle argument that the local context-dependency operates *as though* it were global when it 'shouldn't'! The subtle question is: How is it that we are able to apply this formula, which is only an approximation for small N, and yet derive the correct electron distribution over the set of principal quantum numbers? The answer is that the formula is in a sense 'right' exactly one *third* of the time even for small N - or more pregnantly, networks of small N which have the right kind of 'flawed' structure enable us to use the formula *as though* it were right! (See *4.xiv.*)

xiii.) In section *2.vi.* the generalisation of the Pauli principle to a dipole was proposed, and this result is an example of that generalisation, which applies to *all* of the linear objects in the electron network of an atom, regardless of q-number labellings, and extends arbitrarily to all the molecular and macro-structural connections of the larger network in which a number of atoms is embedded. This effect appears conventionally as the symmetric wavefunction of a chemical valence bond in wave mechanics, and in general we can equate the exclusion dipole with the basis of molar chemistry; but always these results are to be taken in the limit of an underlying *doublet* superspin symmetry. The structure which emerges from the self-consistency condition of the doublets is *essentially* dynamical. The principal quantum numbers and their subdivisions into *s, p* and *d* orbitals etc. are surely not 'parking bays' attached to atoms into which electrons and photons may or may not drop according to various rules, and it is not the 'filled inner shell' of helium which forces the third electron of lithium to occupy a new shell. It is not possible to isolate these approximately-objectified structures from nature because the network condition which generates the rule for *this* atom of lithium *here* does so in the context of generating the rule for *that* atom of beryllium *there* and another of uranium somewhere else. It is the global network condition which matters, the global condition which determines that only certain possible integer solutions lead to *dynamically stable* properties of the network. This general implication is contained in quantum field theories, of course, but there the field is a plenum which inherits divergence problems from the infinite degrees of positional freedom of an infinite volume of spacetime when gravity is introduced. The renormalisation question has yet to be properly understood in any of the varieties of quantum field theory.[5] Looking at this slightly differently, then, it would be useful if self-consistency conditions in a fundamental theory were to demand that universes containing infinite numbers of infinitesimally small objects are not viable universes. In terms of particles and continua such a rule would require that there ought always to be, at some scale however small, *holes* in the plenum, available empty position states for free particles to move into. Given this, one might ask: Why does the centrally-important Pauli principle represent the exact converse of such a dictat, an *exclusion* from position states which an infinite continuum would declare to be available? In terms of a cosmological assumption of isotropy and homogeneity the emergence of structure *per se* can be held to be an unnatural relation, and to maintain that a fundamental empirical principle which limits nature's ability to occupy certain potentials argues strongly for a smooth-field cosmology would seem perverse. But the Pauli principle emerges in a natural relation *if* the global state is not a state of free particles and empty continua, but rather *is a one-dimensional plenum* of linear objects, simultaneously joined to and separated from one another at infinitesimal discontinuities, whose *essence* is mutual exclusion and whose total degrees of spacetime freedom are self-limiting.

xiv.) Consider *Table 3.1.* in which some properties of small-*N* networks are set out. There are two types of network. There is one set of 'closed' networks associated with the integer series of node numbers in column one, for objects obeying the basic network condition that all ends are connected to all others under the super-rule of dipole exclusion. (Hence the absence of 'impossible' configurations such as four antinodes, for example, which automatically goes over to an interconnectivity of six.) And less obviously there is *another* set of 'open' networks associated

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5 Various intertwining offshoots of the renormalisation programme have emerged over the years, from source theory to axiomatic field theory, constructive field theory , *S*-matrix theory and 'Reggeization', asymptotical safety and effective field theory. No solution is fully consistent or fully consensual. See Cao and Schweber [45].

instead with an integer series of vertex numbers in column five. The vertex numbers and node numbers are 'obviously' the same, since every vertex is situated at a node - but they are not necessarily the *same* nodes. Notice that the 'open' networks come in as integer solutions of $(2N)^{1/2}$; but they do *not* arise as solutions of $N = N' (N'-1)/2$, hence they do *not* correspond to any whole number N' of nodes in the left hand column. Conversely, values of N corresponding to the natural numbers of nodes in column one do *not* give integer solutions of the formula $(2N)^{1/2}$, and so appear as fractional numbers of vertices in column five. Obviously this just means that an 'open' configuration is not strictly a valid network in terms of our definitions, and simple consistency would suggest that they be ignored. But one hesitates to conclude that a mere adjustment of semantic categories is good enough, because the configurations which are thus got rid of are those that correspond to atomic electron structure. The fruitful question then seems to be: 'Why would such a semantic ambiguity be reflected in nature?' To see why let's take a closer look at the *Table*.

node no. (N')	antinode no. (N= N'(N'-1)/2)	network state	vectors per vertex (√(2N)-1)	no. vertices (√(2N))
1	0	-	-	-
2	1	closed	0.414	1.414
	2	**open**	**1**	**2**
3	3	closed	1.449	2.449
-	4	-	-	-
-	5	-	-	-
4	6	closed	2.464	3.464
-	7		-	-
	8	**open**	**3**	**4**

-	9	-	-	-
5	10	closed	3.472	4.472
-	11	-	-	-
-	12	-	-	-
-	13	-	-	-
-	14	-	-	-
6	15	closed	4.477	5.477
-	16	-	-	-
-	17	-	-	-
	18	**open**	**5**	**6**
-	19	-	-	-
-	20	-	-	-
7	21	closed	5.481	6.481
-	22	-	-	-
-	23	-	-	-
-	24	-	-	-
-	25	-	-	-
-	26	-	-	-
-	27	-	-	-

8	28	closed	6.483	7.483
-	29	-	-	-
-	30	-	-	-
-	31	-	-	-
	32	**open**	**7**	**8**
-	33	-	-	-
-	34	-	-	-
-	35	-	-	-
9	36	closed	7.485	8.485
-	37	-	-	-
-	38	-	-	-
-	39	-	-	-
-	40	-	-	-
-	41	-	-	-
-	42	-	-	-
-	43	-	-	-
-	44	-	-	-
10	45	closed	8.487	9.487
-	46	-	-	-

-	47	-	-	-
-	48	-	-	-
-	49	-	-	-
	50	**open**	**9**	**10**

xv.) It is immediately obvious from column five that the only antinode numbers for which $(2N)^{1/2}$ gives sensible solutions are the familiar electron shell occupancy numbers, and that each of these integer solutions is bracketed by a pair of non-integer solutions. It is noteworthy that these brackets appear to be widening as N' increases, and indeed they are - as measured by the span of antinode numbers that they contain (increasing by 2 with each triplet). But in terms of their deviation from the bracketed value of the integer, they are narrowing, both as a proportion of its value and absolutely, and this trend extrapolated is consistent with the (unproven) expectation that the deviation would vanish asymptotically in the limit of infinite N. In other words if we see this pattern as the working out of a global self-consistency condition then as we come down to smaller and smaller N (physically equivalent to finer metric scale) the scatter of solutions *widens* around a mean which itself becomes an integer solution of $(2N)^{1/2}$ descriptive of electronic shell structure. And when we look at the solutions it becomes noteworthy that - despite an intuitive expectation one might hold that the stability of an atomic architecture of 'filled' shells would be reflected in 'filled' (i.e., closed) networks - these 'useful' integers label networks that are uniformly *unable to close on themselves* because their antinode numbers do not complete the connectivity of any whole number of nodes; but these are always intermediate between networks that *are* able to close on themselves, these latter paying the 'price' of having unnatural solutions of $(2N)^{1/2}$. An 'open' network of $N = 2$, 8, 18, 32 or 50 antinodes therefore always 'wants' to be completed, and this gives it the especially interesting property that *it can only exist embedded in a numerically larger network*, which demonstrates a natural tension between autonomy and context-dependency in atomic structure (an interesting metaphor for this in the light of the present model might be the concept of *tensegrity;* see *Part 6*) and it produces the inevitability of chemical valency as a requirement of a symmetry.

xvi.) Nature seems to conspire to agree with these 'wrong' numbers which we get only by *abstracting* small subsets from the network as though they were autonomous. It is pointed out that *this is the operation which nature itself performs*, presenting us with atomic subsystems which mimic objectification by spatial separation whilst remaining in all cases (*ex hypothesi)* groups of 'ends' of sheafs of nonlocal objects, such that each group of 'ends' is reciprocal to groups of 'ends' elsewhere. *Table 3.1.* shows why they have to be thus reciprocal and why, paradoxically, a globally stable symmetry is only achievable through a local dynamical symmetry of open, context-dependent systems. It is precisely this 'openness' of atoms to one another which embodies their relativistic 'rigidity'. It is further suggested that the connectivity within and between these groups of doublets could be investigated as the basis of the space dimension of the network, which will obviously not be a global prescription (although it will tend towards - but not reach owing to the self-consistency condition - an infinite-dimensional limit) but will instead be an evolving function of dynamical relationships and be differently specified from observer to observer. Dimension should be context-dependent. In particular one can speculate that the unexpected ambiguity in the characteristic node/antinode numbers of these small networks invites measurement in terms of a fractal dimension. For example, the 18-segment open network of the M electron shell 'lives' on more than 6 but less than 7 nodes; the 32-segment N shell network lives on more than 8 but on less than 9.[6]

xvii.) Prescribing a common numerical size for a sheaf of connections would be to give a value of a 'characteristic atomicity' of the local observables of the network. Evidently the network does have such a characteristic, a fairly complicated one, expressed completely in the series of all the atomic numbers of the periodic table but of the orders 10-10^2, no more. Why is its value small? Or from the opposite point of view why is it so large? More fundamentally, why does such a characteristic exist *at all*? It is certain that physics would be less interesting in a universe with a characteristic atomicity comparable to its particle number! If we express the interestingness that we see in terms of particles

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6 Network dimensionality is scale-free and quantised, not scale-specific and continuous , so the *n* dimensions become assigned to *n* discrete string segments. Particle characteristics in general will be emergent in these collective states, not as properties of individual string segments but "holographically" as distributed properties . With reference to superstring theory, a curling-up or compactification that "contains " *n* polarisation directions can be located as a collective property emergent in this group of discrete 1-spaces. A combinatorial multi-dimensional polarisation -space assembled (theoretically) from such units might encounter certain dimensional phase transitions associated with certain numbers (e.g., 3, 4, 10 and 24). We can see that as real angles emerge in the assemblage of these 1-spaces this can be understood as analogous to a quantisation of curvature. But instead of a transformation applied to a notional flat space of low-order global dimension containing an infinite number of point elements, this "curvature" is radical, and directly generates forms of high-order dimension (high-order spin) - pseudo-objects, crudely isolable as zero vector sums of momenta and in that way coordinatised generally as low-order fractals. Only in the (unrealised) theory limit of an infinite number of string segments does the form of the network approach a smooth curve, and not of a low -order dimension (not being isolable by any real observer as a zero-vector-sum-of -momenta object) but of infinite dimension. So in this case we are supposing, the actual (complex) net dimension will always be much larger than any number of measurable (real) string modes, never smaller, and the critical dimensionality will not now be a generalised space region or scale but rather a numerical constant of some finite series of *actual* operations, instead of being an imaginary matrix of coordinates for an infinite number of *theoretical* operations. (See also *Parts 6* & 7.)

tracking the $1/r$ dependency of an electric force dipole, gravity, etc., have we captured the essence of it? Perhaps not, because we can think of several ways in which this ontology finishes up in phenomenology, or is otherwise not yet satisfactory. So we have to consider that the reason why there is a small but non-zero characteristic atomicity might at a more fundamental level be because this is the way that a maximally-interconnected system of large N accommodates itself through self-interaction to the need for *equipartite* stable forms. An ideal equipartite distribution of network origins or foci is tended towards at infinity for the condition $(2N)^{1/2}$, but for any randomly chosen large real number there will be no ideal equipartite distribution of $(2N)^{1/2}$. It is therefore highly improbable *a priori* that the universe we inhabit would be able to achieve a statical global symmetry, suggesting that it may be a natural condition of the network to self-organise such that a *dynamical* stability can be attained in the *relations* among a large number of states, each an *approximation* to an ideal equipartite solution, leading to the situation of *Table 3.1.* The strategy would be to trade scalar uniformity for vectorial diversity. In the language of the present model this would become a breaking of perfectly-correlated superspin symmetry, which entails a lifted degeneracy in a spin-one photon symmetry generating distance scale in the constraints of Lorentzian spin-half local measurement.

xviii.) In summary, if a dynamical solution could not emerge there could be no physical subsystems, because paradoxically there could be no stability. There could in fact be no quantum theory. An homogenous condition in which it was only possible to abstractly identify 'atoms' as regions with average non-integral numbers of components (like a demography in which families *really* had 2.4 children) would be a pure process in a physics of classical continua. In the sense of this distinction the integral quantum numbers in column four of *Table 3.1.* are *the means of pairs of bracketed classical continuum values* which represent the working out of the Bohr correspondence principle according to which quantum states represent the average values of the classical variable for systems of large quantum number. But in a network model these non-integer deviations do not imply that there is an average value of an actual homogeneous quantity like a metric manifold. Instead of asymptotically definite values arising classically from averaging infinitesimally over stochastic backgrounds, we have here (in miniature, as it were) an ontological realisation of the operational quantum order which implies that perfectly definite values *generate* classical stochastic *foregrounds*. Approximations to homogeneity emerge in special cases. Such a physics is the expression of a *fractal order*, which has far-reaching implications because the simple conditions of that order in our model are entirely scale-free - meaning that cosmological models might be possible which contain fractal matter distributions inconsistent with smooth-field expectations (see *Parts 6 & 7*). Extending the weak context-dependency inversion of the ontological order from the networks of small N to networks of large N leads to an irreducible ambiguity in the interpretation of the correspondence principle, because it cannot be claimed that one or the other point of view is ontologically primary. In other words, normalisation of $(2N)^{1/2}$ across numerical scale becomes indirectly the origin of *physical* scale, and the reason that this is possible - the reason why the universal system of very large N is not just one uniform blob of particles of indefinite extent - is the existence of the generalised Pauli dipole embodied in the locality condition, not of particles, but of doublets, acting across all possible distances of the would-be blob to generate a *pluralistic* spacetime order in which observers are able to appear. In terms of the conceptual toy under development here, this seems to be the proper, and richer, answer to the old question, 'What is the principle underlying the existence of atomic structure?'

xix.) Other implications of these ideas are touched on in *Part* 6. Returning to the epistemology and ontology of measurement in such a system, the important distinctive feature here, introduced by a our nonlocal extended-object construction, is that in a universe of N fermionic 'particles' *any* one state of fermion spin will be found as a measurement on a superposition of $[(2N)^{1/2}\text{-}1]$ spin states because the natural quantum process, of which 'measurement' is a psychologically connoted example, *physically* ***is*** some particular local outcome of the superposition of these states. At this point in order to see in more detail what is happening we have to understand spin as something more than just 'state', and this will mean first elaborating the sketch of our proposed nonlocal object-like network. As repeatedly emphasised, this is offered only as an heuristic toy so I must ask the reader's indulgence.

4. The Superspin Network. Symmetry-breaking and the Emergence of Local String Modes

i.) Superspin is supposed to be carried as a 'super-rotation' of the plane of polarisation of a (linear polarised) photon. The photon itself 'sees' the restored superspin symmetry normalised (in null proper time) to that of a spin-zero scalar 'particle' and is blind to an imaginary torsion which it carries over into the mass relations of a pair of spin-half leptons as a spin-one electrodynamical symmetry. Evidently 'spin' means different things to different particles. More revealingly, 'particle' means different things to different spins, which is a perspective requiring us to think in terms of polarisation. In this view the network is seen as a string supporting a complicated synthesis of vibration modes and their rotations.[7] Thus if we see our elementary object as something like a stretched-out, open-ended superstring, then an ensemble of N two-valued 'particle' states becomes a network of such strings all interconnected at $(2N)^{1/2}$ vertices. This 3D lattice can then be unwrapped in the imagination to become a linear string of such elements all joined end to end. Thus each nonlocal elementary string can be regarded as one of N antinodes in this longer string containing N' local nodes, and in this way the whole string acquires a 'frequency' (though not as yet a real frequency, since we haven't specified any real time or space parameters - see *4.iii* below). So we are imagining a complex network, or a complex standing wave, which has this inherent ambiguity: *Either* it is an excitation where the wave amplitude is the n^{th} partial harmonic of a zero-energy fundamental string mode of indefinite length; *or* it is a sequence of $(n + 1)$ oscillators each supporting a fundamental amplitude driven by resonance. The essential point for the immediate argument is that a *self-measurement* can only ever be made on a node, because this is the locality condition. (This condition can be turned into a selection rule for real or virtual particle states; see *4.vi-vii.*)

ii.) We can see by refolding the string node-on-node so as to reconstruct the 3D lattice that the lattice is an expression of this stringent self-consistency constraint on the string**:** That it can only *self-interact* at its nodes. This may sound 'obvious', inasmuch as wherever it 'happens' to self-interact there will by definition be a node, and there is no *a priori* reason why the folding should not generate an infinite number of nodes given an infinite local 'length' of string. But the useful result is that because the system only makes a 'measurement' on itself at an available node it becomes

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7 The transverse dimensions of these modes are still schematic in this discussion. Briefly, the picture to be developed is that for any 'observer' an *imaginary* oscillation of a string segment only ever occurs locally as a *real* oscillation of string node A retarded from a real oscillation of node B. In photon time these connected states and all parallel connected states are contracted to a spacelike hyperplane containing projections of all orthogonal real oscillations. When this hyperplane is devolved back into a real time representation, the transverse imaginary vibrations living on the intersecting stringy line elements of its hypersurface are summed as photon amplitudes and projected over a dilated 4-space interval as components of a complex wave.

impossible for a new folding, a new act of measurement, to generate a new local node (i.e. by generating a new partial harmonic mode of an interval) *unless the resultant frequency is implicit self-consistently in the the total conservative energy state of the whole string*. In other words for a total number of *N* objects or string-segments, a *new* local node can only occur as an origin of a new set of $(N+1)/(2[N+1])^{1/2}$ *pairs* of observables commuting automatically with all other sets of observables, and an increased local vector potential due to a non-conservation of particle number implies that if the string's total energy is to be conserved then there must also be a compensating potential. Given that the local self-consistency conditions are all satisfied by those vector transformations in which higher spins appear, then the compensation will be such that the adjustment is *fundamentally* an increase in a global scalar potential due to a scalar 'particle' with no (locally conserved) angular or linear momentum. The compensation thus comes in as a negative scalar energy (i.e., negative 'mass'), meaning in turn that we can think of the *fundamental mode* of any (real) interval as an *inflationary scalar particle* or a spin-zero 'inflaton'.

iii. Cosmological inflation is normally thought of as a nonlocal function attached at an early 'historical' epoch of the evolution of a continuous local manifold. In a network this scalar inflaton particle represents the nonlocal interconnectivity provided by cosmological inflation but translated to a time-*free* function, which is arguably more intelligible.[8] It would be a boson in terms of the usual spin statistics, and in a conventional field theory such an inflaton would also be said to give rise to an *attractive coupling* between 'inflaton charges' of either positive or negative sign. But as an element of a network the nested functions become more complicated, so that whilst the inflaton 'exchange' *can* be considered to be nonlinearly attractive between *inflatons* (and thus dual with a deflationary resultant of a global inflationary constraint which represents the network analogue of field gravitation[9]) the coupling *inside* inflatons is a spin-one dipole between fermions, superimposed

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8 The local network potential is *everywhere* nonlocally donated, and the global 'epoch' is a spacelike projection of this function as an imaginary 'history' in which it becomes equivalent to primordial dissipative mixing . A flat overall gravitational potential would occur as the mean of a 'mass dipole ' locally coemergent with scale, where small-scale deflation arises in the context of large-scale inflation giving gravitational contraction inside an accelerating expansion. (See *5.ix*) Because general relativity's field theory would be only an effective theory in a network cosmology there would be no point of singularity . A closer historical-geometrical analogy of the origin of these opposed curvatures would compare the flat scalar potential to a 'braneworld'. It should be noted (although the point can't be developed here) that in the network the function of singularities is *in general* taken over by 4-surfaces, of which the old 'Schwarzchild singularity' of a black hole (presently regarded as only a light horizon embedded in a continuous manifold) would be the type

9 The factor $N^{1/2}$ for the ratio of global to local connectivity in a network of large *N* identifies the cosmically 'gravitational' nature of this function by producing the force constant as $(10^{80})^{1/2}$ or 10^{40} for a universe of 10^{80} particles. See *4. vii.*, note, and *Part 6.*

on the scalar inflationary function of the fundamental mode. There will be no pre-set inflaton charge *or* electron charge. The even-spin inter-inflaton coupling is plurally attractive, whilst the odd-spin int*ra*-inflaton coupling is singly repulsive, and it is the resultant attractive or repulsive character of the action - an emergent function of a 'gravitational' constraint - which determines the local sign of the globally-neutral 'inflaton charge'; and this local action is evidently identical with the doublet electric charge, which is emergently either like/like or like/unlike. So although it is a boson, because of its supersymmetric expression as a mode of a real fermionic doublet the inflaton clearly also obeys Fermi-Dirac statistics. In fact one has to say that it obeys both sets of statistics 'simultaneously' (i.e. in photon proper time) in its complementary guises of charged electron(s) and uncharged photon (see, e.g., *1.ix. & 2.iii.*) This ambiguity seems to be related to the Pauli-Weisskopf [46] interpretation of the Dirac negative-energy fermionic vacuum, which they showed has a duality with a scalar charged boson field described by the Klein-Gordon equation. (The Pauli-Weisskopf scalar field bosons, not being subject to antisymmetric exclusion, would be incompatible with the Dirac 'hole' theory as a model of antiparticles.) This neutral scalar string mode is then rather readily identified - at least functionally, if not formally - as a finite analogue of the zero-point oscillators of the Dirac vacuum.

iv.) In a network model of atomic electrons in equilibrium with a radiation field the origins within the network correspond to $(2N)^{1/2}$ fermion states, each of which subtends $[(2N)^{1/2}-1]$ boson states, and each of these in turn represents the zero-point scalar fundamental of a potential photon vector, analogous to the zero-point vacuum oscillators which allow spontaneous emission of radiation in Dirac's theory. But the Dirac probability of spontaneous emission is proportional to a factor $(N + 1)^{1/2}$ for the condition of an *infinite N.* That is, Dirac assumed that there is no limit to the number of photons that may be promoted out of their zero states by a perturbation of the vacuum, and if that is true then there must be an infinite number of photons already in zero states. The model Dirac developed from this assumption was justified by its results, but it leads immediately to the interaction Hamiltonian becoming infinite and it is then rescued by setting some infinitesimal coefficients in order to keep the transition probability finite. Thus Dirac ushered in the picture which replaced classical empty space with a vacuum filled with zero-point oscillations of energy $\frac{1}{2}\hbar\nu$. But this vacuum is still a continuum, whose infinite degrees of freedom are evidently the origin of the infinity in the Hamiltonian. In a network model no continuum would be available to start with and Dirac's argument from an unlimited radiation density to an infinity of zero-point photon states would be inappropriate. The network would have photon zero states (the half-wave scalar particle modes) but there would be no need to avoid an infinite probability of emission because there *is* a limit to the possible number of real photons of a given state r_γ coordinate at the node of 'emission', corresponding to [$(2N)^{1/2}$-1] fermion position states occupying equipotential levels with resonance r_γ, and the underlying meaning of the coefficient of spontaneous photon radiation is that every fermion *is* a false vacuum of [$(2N)^{1/2}$-1] scalar particle states.[10] Each of these scalar particles is an object or string-segment with no locally conserved spin, what we have identified (*4.ii.*) as the spin-zero *inflaton* mode of the string, partial harmonics of which will then correspond to further boson and fermion modes with locally conserved spin angular momenta. (See *4.iv.* below. It will become important later that this model only allows one such scalar particle per interval as the real fundamental mode; all 'copies' in other modes are either spin-1/2 or virtual spin-2.) But note now that although the scalar inflaton may have no *locally conserved* spin (i.e., neither transpositional-fermionic nor rotational-bosonic) we are not saying that it has *no* spin. In fact we are suggesting that it has a *superspin*, the physical meaning of which will be that it is the *negative* or restoring potential of an imaginary torsion carried as a rotation of the plane of polarisation of a *linear polarised* photon. The photon mediates an electrodynamical coupling which, whilst a dipole, nevertheless always has a positive 'gravitational energy' which is attractive; and a network model suggests that this is because its spin-one vector potential always occurs as a cancellation of the negative inflationary potential of a scalar 'meson' which couples both to it and to an electron doublet, and so a cancelled negative potential appears as a positive energy of 'attraction'. Because this attraction always occurs in the third partial which includes both spin-1/2 electrons/positrons and their spin-1 vector boson its matter coupling can be said to be mediated by a spin-2 phonon excitation, which is the network 'graviton'.

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10 In a network ontology a vacuum state of an infinite number of photons of zero momentum has no meaning except for exchange probabilities involving an infinite number of states of electrons. Since an infinite number of such states (network vertices) cannot in principle be distinguished in any finite region, the probability at any point instant of finding a photon in any state, *including zero*, must be finite . The total possible number of photon states associated with each of $(2N)^{1/2}$ *local* electron position states becomes $(2N)^{1/2}$-1, and these are the zero states of both real *and* virtual photon modes. Thus any single real interaction path between any doublet of electrons *A - B* is a direct route which can be said to be equivalent to roughly this number of indirect routes each connecting *A* and *B via* one of the vertices *C, D, E . . . N'*, like the set of all first-order perturbation amplitudes, and these are automatically summed over as the equivalent least action path *A - B*. In fact for finiteness and consistency *all* network diagrams to all orders *must* obviously sum over to the local action of *any* uninterrupted (least-action) network segment. What enables this condition is the fundamentally nonlocal renormalising of the vacuum gauge, segment by segment (i.e., superspin), inside a constant scalar potential, which is equivalent to a vacuum gauge of constant norm inside a varying nonlocal scalar field potential. So one can see that this self-consistency condition expresses the emergent *dipole* potential of an underlying neutral scalar *inflaton* symmetry. The dipole balance of positive and negative 'corrections' due to the local *form* of the directionally-quantised inflaton 'field' represents the metrical accommodation of *A - B* to the sum of all possible perturbation orders . In this rather formal sense it is possible to say that a pathological divergence of virtual states is checked 'by gravitation'. See *4.vii*, note *10*, & *Part 6*.

v.) When the locality condition of self-interaction is applied to a set of such scalar elements the vector transformation requires Lorentz invariance to be emergent in the 'folding and refolding' of the string, node-on-node, under this multiplying scalar potential, and the real SR 'distances' which result must each express a changing real energy over a changing real *time*, preserving the action product as a constant of 4-space rotations. Now an intriguing surmise is that the untransformed (inflaton-mode) scalar potential of each interval *is the origin of the Planck constant, recovered as the common extremum of all local action vector transformations*. Beginning with the assumption that the spin-zero eigenvalue represents the QED basis state for a gauge particle of spin-one (and remember that physically this basis state enters as the fundamental mode, one half-wave-antinode long, of a string segment confined between self-interaction nodes) we introduce (see *1.ix.*, *4.iii.*) the concept that the spin-zero function is actually degenerate in the *two* eigenstates of a super-rotation, θ_s, which is unperturbed *by* the local magnetic field (being in fact its prior generator; see *Part 5*) but which may loosely be considered to be perturbed out of a false vacuum state by a superspin 'field' which does not couple with photons alone *or* with electrons alone but only with the dynamically-supersymmetric doublet state *electron*$|\uparrow\rangle$ + *electron*$|\downarrow\rangle$ in the form of *photon*$|\uparrow\rangle + |\downarrow\rangle + |\theta_s\rangle$. Because of the Pauli exclusion principle (appropriately generalised to a dipole - see *2.vi., 3.xi-xii.*) this means that the degeneracy exists in a pair of 'electromagnetic field' coordinates and is lifted in the form of a *displacement* of a pair of local position observables linked by a photon (null signal line). By analogy with the classical magneto-optical rotation we suppose that this coupling effects an axial 'specific rotation' $\theta_s = \lambda\Theta_s H_s l$, where Θ_s is a constant, H_s is the (notional) superspin field strength and l is a path length. Where wavelength λ, path length l, and 'field strength' H_s are all normalised to unity, the specific rotation of the vacuum state reduces to Θ_s. Evidently therefore the scalar 'inflaton' mode sets a constant specific rotation Θ_s equal to the common zero point of local spin angular momentum and magnetic moment. This means that whereas a classical analogy might suggest a 'gyromagnetic ratio', $g_{s,}$ of our superspin doublet vanishing away in the scalar case, there is in fact still a degenerate eigenstate which is unperturbed but cannot vanish. Therefore we set this false-vacuum state of g_s as just the proportionality 1.0 so that all our other factors remain rational. Now the value of Θ_s remains indeterminate, but since it is to be a rotation of phase we know it will be expressible as some multiple of 2π. The factor H_s will remain unity since we don't wish to import any continuous field potential as primary, and effectively it drops out. So, we can put

$$\theta_s = \lambda(\Theta_s/2\pi)l \tag{4.1}$$

But with pathlength and wavelength both normalised to unity even the λ and l drop out leaving simply $\Theta_s/2\pi$. To get from this imaginary scalar case to the first vectorial case of real interest we have to introduce a real *time* and a real *energy*. These will emerge along with a measurement of a wave number smaller than 1/1 made by a self-interaction of the folding string. But at present we have no idea what these values should be so we insert a phenomenological factor, *h,* an action containing an energy and a time, to be determined by experiment. Now, setting Θ_s equal to one for that experiment and multiplying by h we thus get to $h/2\pi$ which we can take to represent an extremum of every vectorial case. (We set $\Theta_s = 1$ because we know *ex hypothesi* that a photon in any local measurement does not 'see' a superspin $\Theta_s h/2\pi$ and of course neither do we - directly. But we do see h.) This factor h is still arbitrary but it allows us to retain λ also, and with λ we can start to produce a series of quanta of length, as wave numbers, ratios of the *half*-wave spin-zero fundamental mode, giving

$$\theta_s = h/2\pi(\lambda/2, \lambda/3 \ldots \lambda/n) \qquad (4.2.)$$

which relates discrete values of specific rotation to a series of increasing frequencies as a function of the quantum unit of boson spin.

vi.) Now at his point we should pause, because how we interpret higher partial modes depends upon how we characterise the process. According to the inherent ambiguity mentioned in *4.i.* above we can say *either* that each new antinode is an excitation in the *n*th partial of a zero-energy fundamental string mode of indefinite length; *or* that it is one of a growing sequence of (n + *1*) oscillators each supporting a fundamental amplitude driven by resonance (we will have to introduce and justify a selection rule in due course to resolve this ambiguity in realistic cases, but for now the underlying ambiguity is the important thing). For example, a whole photon wavelength contains a node at π, and terminates at a node after a further 180-degree rotation to phase at 2π, so that the spin-zero scalar fundamental now contains *two* antinodes, each *fractally similar* to itself, in the form of two photon half-wavelengths. Treated as belonging to a series of separate oscillators, each one of this pair of new antinodes represents only a scalar increase in a gauge potential in respect of local forces (see *3.x.* above), so we have a degeneracy in the two states with the identical unperturbed energy eigenvalue. But this scalar potential also represents a quantum of *superspin* which is to acquire a value with the breaking of a generalised nonlocal symmetry to a restricted local spin symmetry so that its trace, h, appears as the energy/time dimensions of a spacetime action. In other words, although we say the superspin is carried as an *imaginary* rotation of the photon linear-polarisation plane (spin-zero transforming to spin-one as a local displacement but hiding an imaginary extra torsion that the photon does not 'see') it does have a real projection on the nonlocal axis of electron intrinsic spin as a function of space relations generated in relativistic electrodynamics.

vii.) In this view the new antinodes belong to an excitation at some increased standing-wave frequency of the entire string and are not simply two new scalar potentials but two components of a new partial mode with a relation to a *frequency.* Now an increase in the gauge potential becomes a contribution to a total *real* energy elicited according to the locality condition of the self-interaction in which SR time (interval) is emergent. Thus transformed with a time each re-gauging of the emergent vector potential at successive nodes is effectively a new zero-energy false vacuum state. Each successive zero-point raises the gauge by an imaginary advancement of phase, a *superspin* rotation (or its negative) which appears in the balance ledger of local forces as an effectively scalar lower bound to the production of energy with time or just the action constant *h*.[11] But because time is emergent in relativistic measurement only as a function of photon wavelength (the momentum, and therefore the velocity, is completely indeterminate in less than a wavelength) there is a natural minimum of electromagnetic spin which we find by allowing the oscillators to be measured by the photon mode. For this measurement they become components of the whole photon wavelength, another excitation in another partial harmonic of the whole 'string', where they become twin antinodes in the *third* partial mode of the fundamental (we'll see what happened to the second partial in a moment) whose reflected phase angle rotates through a total, as measured in the effective unit time[12], of $h/4\pi$, or spin 1/2. This is the electron-positron mode of the string, paired

11 This gives rise to a range of equivalent arbitrary conventions for expressing fundamental 'constants'. If *h* is considered to be held constant under superspin transformation then it becomes possible to say that *c* is a constant of varying norm, or *vice versa*. Newtonian physics can be recovered from relativistic quantum physics by setting *c* at infinity and by setting *h* at zero. Thus, described as a cosmic 'history' in imaginary time, the incremental 'folding' of the string as it evolves through the series of modes can be thought of as a process analogous to a dispersion through a series of *N* different vacuum refractive indices, generating *N* emergent finite norms of *c* which sum over as the imaginary 'curvature' of GR spacetime with *h* notionally constant. Renormalizing *c* to a flat space would be equivalent to allowing a local variation in the norm of *h* for differently accelerated observers. Therefore since the total number of different real accelerations equals the number of 'folds', equals the number of network vertices, equals $N^{1/2}$, we can see that the negative or restoring potential of gravitation becomes a global renormalisation of the action gauge equivalent to a sum over the local restoring potentials of superspin. See *4.iv*, note *9*, & *Part 7.*

12 Unit time can be any one of 10^{40} projections of unit distance each specified at one of 10^{40} network vertices, and unit distance is of course l/2. Unit time is therefore order of 10^{-15} second for visible light . So the choice of unit time is arbitrary, but only to the extent of electing one of the finite number of self-observations allowed by the network. 'Observing' a node in a higher partial (at a higher frequency) represents a finer localisation of 'an electron' not because it illuminates some occult particle more precisely but just because 'an electron' *is* this act of self-observation and so 'occurs ' at any frequency at which an observation may occur. It is possible to think of an electron as just the sum of all

virtual amplitudes of the photon mode having equal and opposite spins that rotate into one another over 720 degrees of phase in unit photon time. So we have in the 'ground' states of each network element or string-segment: a spin-zero scalar boson, a photon, and an electron-positron pair, all *scale-free*, unit distance being normalised to one wavelength and velocity normalised to unit scalar speed (c). These will be the lowest modes of every segment.

viii.) In any possible local view, the inflaton mode would look like a spin-zero particle with a zero positive mass - a Goldstone boson, with a zero local potential - but its *superspin* is the origin of a *non*local potential, a restoring potential which, as mentioned in *3.x.*, will be just the negative of the imaginary photon spin that carries the broken electron-spin correlation symmetry. A real photon spin being associated automatically with a positive-momentum real propagation vector it can be inferred that an imaginary photon spin is associated with an imaginary propagation vector and a *negative momentum*, a negative mass-energy, which is why it will be inflationary. (As mentioned in *2.iii.* this mode does have a local function in this ontology analogous to that of a Higgs boson in the standard model, since it becomes the origin of inertial mass, but the mechanism is different in that it is identically the origin of gravitation as well. This satisfying ontological parity lacking is in the standard model. See *Part 6*.)

ix.) Consider the fundamental scalar mode of the string as 'seen' by a photon, whose local spin $h/2\pi$ is the constant of a gauge symmetry which untwists local spin-zero (or a *specific rotation* θ) to its normalised vector identity spin-one, as

$$\theta/\lambda = (h/2\pi) \tag{4.3}$$

where wavelength, path length and magnetic field coupling strength are all set equal to one. That is to say, by analogy with the electron magnetic moment

$$\mu_{eB} = eh/4\pi m_e \tag{4.4}$$

we can suppose there would be a *notional* photon magnetic moment

$$\mu_{\gamma B} = eh/2\pi m_\gamma \tag{4.5}$$

which of course equals zero for a photon, even though it has spin-one, because the photon charge is not e but zero (i.e., the radiation statistics are linear, or two photon modes do not directly self-interact[13]). From one point of view this is because its quantum spin state is degenerate in the two opposite electron-positron spin states, $\pm eh/4\pi m_{\pm e}$. That is to say, a photon has these two spin eigenstates which are not (normally) both lifted out of degeneracy to acquire distinct eigenvalues.

its intersecting virtual photon modes.

13 Using intense lasers coherent photon modes can be made to couple inside certain materials.

From another point of view the fact that the photon charge is zero means that its rest mass m_γ in the denominator of (4.5) does not appear, which conventionally would be taken to mean that all of its mass is dynamical - it vanishes 'at rest'. But notice that m_γ must be non-zero for the magnetic moment to be zero in (4.5). If m_γ is *not* non-zero in the absence of charge then the magnetic moment becomes infinite. Conventionally this would mean that (4.5) could be dismissed as a meaningless over-complication of the fact that the photon carries no charge and thus cannot have a magnetic moment. But if one takes seriously the idea of increasing the number of basis states of the photon it becomes possible to suggest that there must be a degeneracy in the photon eigenstate for mass.

x.) This degenerate photon mass can then be considered to be cancelled by the negative mass of a scalar boson, only appearing when the degeneracy is lifted and 'it' donates this mass to an electron in the emergent electrodynamical symmetry, as has already been suggested. This recalls the *f*-field theory of Pais [47,48] that would allow an electron to couple both to photons *and* to a compensating field of scalar mesons. The purpose of Pais' model was to rescue a finite electron self-energy, as was the equivalent scalar *C*-meson hypothesis of Sakata [49] and Tomonaga [50]. This 'cohesive meson' was introduced by Sakata to absorb ultraviolet divergences in the theoretical electron mass. Later, it was invoked by Tomonaga as a way of cancelling a divergence which appeared in calculating radiative corrections to the Rutherford scattering of electrons. Tomonaga pointed out that this divergence could be identified as a photon mass, but the problem with this interpretation was that there was no photon mass term in the Maxwell equations into which the divergence could be assimilated, so Tomonaga suggested that a hidden photon mass might be compensated by a Sakata-like *C*-field. But although these models were important in the development of renormalisation theory in the 1940s and gave clues to its eventual more 'technical' formalisation by Schwinger [51], the whole development presumed the underlying framework of a problem that can be split into an unperturbed radiation field and deviations from this unperturbed state due to interactions that are then superimposed upon it - the essentially classical metrical space field with quantum attributes imported.[14] Consequently the relativistic gauge invariance of this ruling field-theoretic paradigm

14 In Schwinger's model for the interaction of a free matter field with a free radiation field the quantisation of the radiation field is effected by dissolving the metric manifold to an infinite number of geometrical points on an evolving spacelike surface , to each of which a time can be assigned - the 'super many-time formalism' based on the earlier many-time theory of Dirac and Fock [52]. This enabled the evolution of quantum states - hitherto represented by a common time variable for different spatial positions - to be made relativistically covariant for all observers, with the Schrödinger equation's common time now being associated to the infinitesimal displacement of a spacelike hyperplane whose point elements could be treated somewhat like particles. With this relativistic covariance in place the infinities can be handled as a constant background and subtracted from the experimental electron energies so as to preserve sensible answers.

could not entertain a photon mass and Tomonaga's idea was discounted. Yet in the unified gauge theories of a later era the concept of spontaneous symmetry breaking shows that a photon can acquire and lose a mass. This is a phase change re-enacted in the laboratory during the warming transition of electrons out of the superconducting regime, when the broken electromagnetic gauge symmetry is recovered and photons which had been limited to short range by acquiring a mass now lose that mass so that the magnetic field penetrates back into the conductor and electrons reacquire inertia (see *2.iii.).* In this sense an increase in the number of quantum basis states of the photon is an increase in the space of states for a supersymmetric doublet containing two (broken) superspin symmetry phases, and although one way of looking at electron inertia is to say that it represents a lifted degeneracy in the photon eigenstate for mass the proper perspective would be that of the superspin 'field' which couples with both electron *and* photon.

xi.) The question of what possible meaning can be given to a state of a photon which is ontologically *prior to* the electrodynamical symmetry in which it emerges as the gauge boson is thus to be answered in terms of this superspin symmetry. The meaning of a photon rest mass which doesn't manifest will be basically the same thing as a zero-point photon state in the Dirac equation. The state in which a photon rest mass doesn't manifest can only be a state in which a photon doesn't exist at all! (In one sense, then, we are giving this rest mass back to the spin-zero scalar particle from which our photon derives, which in terms of this model becomes the equivalent of a 'Higgs particle'; but clearly this is not any distinct real mode of the string.) This state in which a photon doesn't exist is one of the complementary pair of 'stationary' states when a photon gains/loses a quantity of momentum $p = e/c$ and appears/vanishes by 'emission'/'absorption' from/into an electron excitation. So the notional photon rest mass never appears although it is conserved within the doublet. In this sense the photon rest mass does exist as the energy of a stationary oscillation in the first partial mode of the spin-zero scalar Goldstone boson mentioned previously. From the equation $E^2 = m^2c^4 + p^2c^2$ we can get the energy of a 'stationary photon' by taking the square root, and the momentum term drops out to leave just $E/c^2 = \pm\, m_\gamma$. Proceeding as for Dirac hole theory we take *both* solutions; but instead of saying that one of a pair of alternative potential outcomes is almost always excluded by a highly asymmetrical context (like the 'sea' of occupied negative states in hole theory) we accept a general cancellation of two opposite *simultaneous* mass-energy eigenstates of this stationary wave (in the *spirit* of the Pauli-Weisskopf model; see *4.ii.*) whose resultant is a

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Feynman's [53] parallel development of the renormalisation procedure out of his action-at-a-distance-to-path-integrals programme involved summing discrete spacetime processes instead of differentiating over continua. It was essentially an *S*-matrix theory about collision processes , even though renormalisation is a perturbative tool of field theory. Looking at the function and the spirit of this whole enterprise, one could speculate that it is yearning towards the kind of radical deconstruction of the continuum offered by a nonperturbative scale-free network model.

massless spin-one photon. The lifting of the degeneracy in the photon mass is then due to a spontaneous symmetry-breaking *generating* a measurement context, such that whichever of the non-degenerate states appears in local 'measurement' will be by definition positive-real. And thus we arrive generally at a manifest positive mass-energy mc^2 being the rest energy of an electron - and bringing in the charge as in (4.4) - together with a *negative mass-energy* equal to $-mc^2$ remaining hidden, 'associated' both with the photon and with the electrons it connects - that is, with the null world-line of the whole doublet system - yet not appearing in any local audit of their positive energies. This system thus becomes a complex emergent state of a spin-zero inflaton whose imaginary amplitude varies like the phase speed of an emergently real photon wavelength.

xii.) A local measurement context in which this wavelength emerges elicits generally an electron ($+m_e = -e$), but the corresponding positron state ($-m_e = +e$) generally is not elicited locally *because the superspin symmetry is broken* locally. The resulting specific rotation θ_s wrecks the correlated spin-one state in which virtual electron and positron are always paired, and it is this rupture which births the photon as carrier of both the electromagnetic gauge and the (hidden) torque of superspin. This role of the superspin can easily be seen from the fact that the rare events in which positrons are locally measured are always pair-production events in which a spin-one Bremsstrahlung or gamma γ decays to an EPR-correlated electron-positron pair conserving the total entangled spin. Unlike the generality of spin states whose pairings are broken in the transition to local spacetime invariance, these entangled pairs should 'feel' no restoring torque from a hidden superspin, meaning (*ex hypothesi)* that they will not experience the normal electromagnetic gauge coupling of a pair of unlike charges.[15]

xiii.) Note that, as emphasised before, the coupling of matter to its scalar inflaton mode becomes the 'role' of the photon, in the sense that the real timelike displacement of charges in real $< c$ observer frames, and the photon superspin, are dual representations of the gauge renormalisation between spin-0 and spin-1 embodied in the photon mode. Only when the nonlocal superspin symmetry breaks to a local electrodynamical symmetry of photon and electrons in this third partial mode of the string does a higher-order *phonon* spin emerge which represents a mode of induced attraction

15 The implication being that recombination of a pair that remains purely entangled is only a *virtual* annihilation of *virtually* created particles. Interactions in which antiparticles are 'observed' - i.e., transfer real momenta - thus represent disentanglement, and restoration of the electromagnetic gauge within which locality is protected. When we use a neo-classical electromagnetic field as the 'environment ' for decoherence it brings in an infinite regress of virtual interactions. But we can see that 'virtual' states on the network are robustly virtual and that uncontained proliferation does not arise.

between inflatons whose nonlinear self-coupling is repulsive in the unbroken superspin phase. 'Normally' a spin-zero scalar field couples only to the trace of the stress-energy tensor and therefore would not couple to the electromagnetic field since the 4-space electromagnetic tensor is traceless. Thus it is conventionally held that because a scalar boson exchange cannot couple to a spin-1 photon then gravitation, which by definition does couple to the energy of photons, must be mediated by the next even-integer spin mode available - hence the spin-2 graviton. In our network model the 'graviton' becomes the spin-2 phonon mode of the induced inflaton attraction under spontaneous superspin symmetry breaking. Hence in entangled electron-positron pairs where that symmetry remains intact one expects the *converse* both of the normal electromagnetic and of the normal gravitational couplings to be observed - i.e., opposite charges whose electrical potential is generally considered attractive will energetically 'de-annihilate' and fly apart in a spin-singlet state with a total spin-angular momentum of zero, as observed, preserving the scalar mode of inflaton repulsion. Within strictly redefined limits, therefore, the network model implies that pair creation represents 'antigravity'.

xiv.) In Dirac's 'hole' theory positrons are negative energy states, and this holds in different representations. In Feynman's spacetime representation, for example, the antiparticle's action is a sum over negative energy states equivalent to inverting the time variable in the causal propagator, whereas in hole theory both positive and negative energy states evolve in a forward time direction. In any case the positron energy is $-mc^2$. Conventionally speaking the gravitational mass of $-mc^2$ is equivalent to that of $+mc^2$ because mass-energy is a scalar monopole charge and the gravitational potential is a global field. Experiment so far suggests that negative antiparticle masses 'fall' in this field just like positive particle masses [54] but this answer is not precisely pertinent to the question posed here *a propos* correlated singlets: The precisely pertinent prediction of Newtonian or GR-based field-gravitational theories is that the electron and positron exert a gravitational force *on one another* proportional to these two masses. In the network model gravitation is no longer a charge coupling with a field - it is one emergent pole of the *scale-specific dipole* and there is no direct dependency on an attractive global field potential.[16] Rather the 'attractive' field potential is a

16 Imminent (September 2002) experiments with the first substantial batch of cold antihydrogen at CERN are likely to assume such a condition and so test only for the 'conventional' equivalence of antiparticle masses under terrestrial gravity. A recent review for ESSA by Bertolami and Tajmar [55] identifies as worthwhile an International Space Station experiment to search for violations of the weak equivalence principle by antiparticles in microgravity, but again such a search would be insensitive to an inflaton coupling which is only manifest in the unbroken symmetry phase and is constructively the same as the total pair-momentum. There will be novel difficulties in understanding how to unify the spectrum of 'forces ' in a fundamentally monopolar network theory. These are clearly not only theoretical and practical but also semantic, owing to the ingrained assumption that GR must be a long-scale, low-energy limit of a short-scale, high-energy quantum gravity theory, such as Planck-scale loop quantum gravity. The network quantum theory imagined

construction put upon the mesoscale (classical) resultant of the generality of particle doublets where superspin symmetry is spontaneously broken in favour of $+mc^2$; but this does not imply that 'particles' are sources of such central force potentials in miniature, and in our model the electron and positron *do not* exert a gravitational force on one another, although their action is of a kind which, in the large, is the generator of a local gravitational potential. Remember that a degenerate photon mass is considered to be cancelled by the negative mass of a scalar boson, only appearing when the degeneracy is lifted and 'it' donates $+mc^2$ to an electron and $-mc^2$ to a positron in the emergent electrodynamical symmetry (*4.x.*). Thus whilst the electron-positron pair preserves this cancellation this is because it fleetingly resists the breaking of its superspin symmetry, preserving an overall vacuum state of zero rest energy. This is equivalent to conservation of photon momentum in a virtual pair-creation, in the sense that all quanta in our closed network 'cavity' can be considered to be virtual; and the zero gravitational potential of such a pair 'explains' the zero cosmological constant of flat space, in the sense that the network contains only such virtual 'vacuum fluctuations' as may be considered to be contributions already factored into the 'experimental energy' of the whole.[17] A total energy difference of $2mc^2$ is not a gravitional potential because inertial mass will only become a locally emergent *product* of the global inflationary dipole in the same symmetry-breaking that maintains an asymmetry of positive real-time electron interactions *via* the annihilation of the positron. In other words, the gravitational potential is not generated by an internal attractive coupling due to mass - on the contrary, mass is an emergent local transform of the global inflationary potential, a renormative 'constant' varying reciprocally to c, and the pair's temporarily-preserved *internal* charge is the *inflaton* charge, expressed in the nonlocal entanglement of a correlated spin-singlet. The 'gravitional' coupling is a higher order *phonon* coupling across multiples of $\lambda/2$ (see *4.xxi.* below), and gravitational potentials will be emergent (locally) proportionally to a scale factor and (globally) proportionally to the asymmetry of 'matter' over 'antimatter'. (Thought of in terms of a network of Feynman-like diagrams this latter proportion would be the mean fraction of string segments with negative time variables. Cosmologically this implies an effective gravitational coupling varying proportionally to the mean free path of a positron, which can be used to index a varying cosmic mass-energy density. But in a network model there will be no globally-varying gravitational 'constant'. Instead of an objective history of a globally evolving space field we will have 10^{40} observers each renormative in relation to floating 'constants'. There will be no true

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here would not be a short-scale theory but a scale-*free* theory, to which the connotations attached to the concept of a 'weak-field limit' would fail to apply.

17 Inverting the usual theoretical philosophy:- The renormalisation of network constants node by node, which is the effect of superspin (see *4.vii.*, note *10*), represents a physical *identity* between their *effective* values and their *normative experimental values*.

gravitostatic field coupled to a global mass-energy density. This cosmic field becomes an imaginary projection from local real gravitomagnetic displacements. We can think of the (electro)magnetic field as a relativistic deformation which *is* SR spacetime. By analogy we can characterise the gravitomagnetic field as a deformation which *is* GR spacetime, and extending the analogy we can suppose that where the electromagnetic field is a theoretical index of changes in relative +/- charge density for differently moving charges [see *Part 5*], so the gravitomagnetic 'field' is just a corresponding theoretical index of changes in relative +/- *time* density for differently moving masses.)

xv.) The energy of the vacuum and the energy of the network are obviously constrained to be the same quantity differently conceptualised, as we will now see. So far we have been considering the lowest modes of any given string segment, which are crudely-speaking equivalent to the first-order interaction terms of a field theory for a radiation field containing a pair of charges. Now it will be evident that as higher partial modes are considered a 'new' node may be either real or virtual depending on context. For example, it was said above that the first partial, with one node, gives a photon. We can say that considered as belonging to the first partial mode of the *entire* string this node cannot be real, because our locality condition forbids self-interaction without a self-consistently available node (there may be esoteric arguments around this, but cosmological implications can be discreetly left to one side for now). But once we have several objects or string-segments to work with we can start to have consistent 'observation' by self-interaction and very quickly large numbers of superposed modes become possible. Evidently any other fractally-identical spin-one pair of antinodes anywhere on the string can also be identified as a photon wavelength. In fact *any sequence* of such wavelengths can also be a considered a photon of arbitrary energy $h\nu$, since the quantisation condition contains an arbitrary time. Not all photons will be real (in the sense of being an observable), because the only meaning that SR and QM give to the question of whether a photon is or is not an observable is in the form: Is there, or is there not, an excitation of an electron to a set of higher energy eigenvalues? An observed photon therefore *is* a state of an observed electron, so that (one 'end' of) a real photon only occurs where there is (one 'end' of) a real electron doublet. This means that the mode of the string in which each is theoretically 'found' contains the same self-interaction node, which is a vertex of the network, a folding together of $N^{1/2}$ string segments, identified by *changes of momenta.* For electrons and photons their coupling is a transfer of momentum, which is possible because their modes share vertices. Coupling occurs at a resonant frequency because they live on odd-numbered partial modes. This is why the second partial mode between photon and electron modes is ignored in the analysis of *4.v.* above: it is an even-numbered partial mode with three antinodes and is therefore a virtual mode corresponding to spin-3/2 (conventionally-speaking, a 'gravitino', the superpartner of the graviton) which does not have a direct electrodynamical coupling.[18]

xvi.) There can be many higher-frequency non-resonating boson and fermion modes in any one string segment as well as many lower-frequency non-resonating phonon modes living on string lengths many segments long, none of which are observables at the natural frequency of the string segment in question. All of them may have real forms, either on a different group of string segments or at an altered natural frequency of the same string segment(s). Since that natural frequency is a function of the entire string network it may change, and a node may be generated, or the local Lorentzian geometry might change, bringing out a set of photon resonances over an entirely different range of frequencies in a new self-consistent 'observation'. The superposition of all possible modes will therefore be very complicated, with the following selection rule operating to distinguish real and virtual modes: In general, for any constant real length of confined string, the set of all odd-numbered string modes (1, 3, 5 . . . *n*, where the fundamental = zeroth mode) gives self-consistent interactions reinforced at *one* possible set of standing-wave nodes; whilst the set of even-numbered modes (2, 4, 6 . . . *n*) gives self-consistent interactions reinforced at *another* possible set of standing-wave nodes. In general these sets of modes will reinforce one another only occasionally, but because there is no such thing as a constant real length of confined string (the network is dynamical for any real observer) the distinction becomes academic, with odd and even string modes, and real and virtual frequencies with their different fermionic/bosonic spin modes transforming in and out of one another in an incalculable cosmic Fourier synthesis.

xvii.) When we focus on observables, transfers of momenta at vertices, then we normalise the network to a particular node where a self-interaction of the string equates (depending on context) either to the emission/absorption of a photon by an electron or to the annihilation of a photon and the creation of an electron-positron pair. If the node is self-consistently reinforced so that it approaches 'permanence' then repeated self-interactions of the string at that node measure 'an electron' and the interplay of wavelengths around it becomes analysable into real photons, virtual photons, and virtual electron-positron pairs, emitted and absorbed by it. If on the other hand the self-interaction is not a 'permanent' equilibrium condition but exists only as a fleeting resonance then a photon annihilates into a virtual electron/positron pair that each separate off into the network

18 This may be related to 'Furry's theorem'. As later rediscovered by Feynman and applied to Dyson's renormalised *S*-matrix, Furry's theorem states that all of the diagrams with odd numbers of loops automatically cancel out of the perturbation calculation and therefore do not contribute to the scattering potential. In terms of the network such 'loops' are automatically self-consistent routes within it, and it is an expression of this self-consistency that all contributing routes for electron/photon interactions will occur only in odd-numbered modes which have *even* numbers of antinodes, because only in these modes can the nodes of 'emission ' and 'absorption' coincide. Even-numbered modes which have *odd* numbers of antinodes (= loops) have no coupling and so are virtual in relation to a particular local scattering event, to whose amplitude they do not contribute. They do contribute globally, of course.

to spawn other photons, or *vice versa*. Overall this has obvious similarities to resonances of the Heisenberg scattering matrix and the Wheeler [56] *S*-matrix view, and pictures can be drawn that resemble interconversions in the Chew [57] 'democratic' hadron bootstrap. The elicitation of 'real' object states can be identified with *(a)* pairs of 'elastic scattering' events, pairs of nodes at which changes of frequency accompany changes of velocity, as opposed to *(b)* pairs of onwards inelastic scattering events without momentum transfer, which may be *the same 'real' pair of nodes seen in a different scattering channel* where the entire 'interaction' remains virtual. In the case of *(b)* there is (ideally) no momentum change along an uninterrupted straight channel, therefore no observable event, meaning that although each of the nodes can be said to correspond to *some* photon mode on that sequence of string segments they do not both correspond to the *same* partial mode. Each may be a terminus of a 'real particle trajectory' as paired with another node elsewhere, but they may not be paired as real with each other. In the former case *(a)* there is a dog-leg channel with two momentum changes, two real observables, and our local view may therefore be of two collisions on a single perturbed particle trajectory (for example), or of three different interconvertible particles, or of a vacuum particle promoted briefly to reality between two points of creation and annihilation by high-energy photons. These would then all be different context-dependent views of the same substructure - three complex linear oscillators or string segments - where the distinction between real and virtual particles, like that between bosons and fermions, disappears into a supersymmetric complex identity.

xviii.) Note the fact that where there is this dog-leg of momentum transfer between segments the Lorentz-invariant transformation of the underlying structure now looks a little like a problem concerning the rigidity or tension of three segments *AB*, *BC*, *BD* linked at *B* and *C* with the resulting force couple acting as a turning moment on a central element *BC*. But in this purely Lorentzian transformation it only *looks* like such a problem because of the locality. Because of the limit of the speed of light information about forces acting at the junction *C* is not available simultaneously anywhere else, say at the junction *B*; indeed if the messenger is characterised as a fermion the momentum information is carried by it even slower. Therefore a reaction at *B* should be causally independent of a reaction at *C* because, as we conceive it, *B* is *'in the past of' C* and cannot be acted back upon by a force applied at *C*. Yet if *B* and *C* are local labels that live on a nonlocal object *BC* then there may be a nonlocal 'force couple' producing a turning moment on this object even though *B* is outside the light cone of *C*.[19] This is a locally measurable effect because of a constraint which the nonlocal symmetry imposes on the local. We can expect this moment to be negligible (in relation to Lorentzian local forces) when the length scale of *BC* is large, but significant when the

19 The Wheeler-Feynman action-at-a-distance theory of electrodynamics does include a back reaction from a future event through the radiation field, which represents a duality with the nonlocal network model. See *Part 6*.

length scale is small, meaning that as the nonlocal object *BC* approaches characteristic 'inter-particle' dimensions rotation becomes general for pairs of local observables, and the nonlocal generator of this rotation will be found to be a constant, as we will now show.

xix.) Only the nonlocal 'preferred frame' of the scalar inflation is describable as a frame where, with perfect generality, the vector sum of all linear momenta is zero. So, when we now consider the underlying structure of three linked elements subject to a force couple acting as a turning moment on the central element we can see that this will in fact occur as the general case where there is a 'particle trajectory' between junctions of momentum channels (i.e., self-interaction nodes of the network) because the inflaton charge means that the arm of the 'force couple' must always be of non-zero length, even in the low energy limit, whilst the action of the couple will reduce to similar inflationary 'forces' at the points of application in the same limit. Therefore the context for the emergence of local forces includes, quite generally, a probability of a local turning moment due to a non-zero inter-vertical separation in the 'foldings' of the string, which itself expresses the nonlocal torsion of the superspin. Every element of our ontology will have different Lorentz-invariant projections for differently moving observers, which can be thought of as rotational foreshortenings of the linear momentum four-vector in 4-space where the total scalar energy transforms in every frame like a different time, and these transformations will converge to a common extremum setting a lower bound to the action of every interval which is the inflaton potential. But importantly this common extremum will have only real vectorial expressions for real observers. The constant inflaton potential acquires a constant metrical expression only in a theoretical scalar limit, and such a global/imaginary limit of the network is not approachable as a local/real state. In other words the 'Planck scale' is not a natural unit distance. The inflaton potential is a constant of a *scale-free* unit distance in this theory because unit distance is just $\lambda/2$.

xx.) From one point of view this is because the superspin inflaton potential is an action. It is a vectorial constant of all real projections of unit distance, an expression of the specific rotation which we introduce again as a phenomenological factor set at 1.0. This will be equivalent to the relativistic 4-distance s^2 normalised for natural units of h, c and λ. There is a real value to be discovered by experiment which will be different for every real $<c$ observer, and this is the projective mapping of unit distance as a population of actions transforming onto one another by 4-rotations. Among this population of improper dilations of unit distance relative length scale emerges, expressing the proportionality of superspin to wavelength in terms of intervals of time. This 4-rotation contains the idea that there is a uniform translation of all objects through 4-space at c and that every real action containing a velocity $< c$ is a transform of a 'hidden' angular 4-momentum. The domain of real dilated distances is therefore bounded by a limit at c in which no linear momentum has an observer transform as an angular momentum (i.e., an interval of particle translation is null, or s^2 goes to zero), and a limit at h in which no angular momentum has an observer transform as a linear momentum (i.e., particle 'intrinsic spin' is not a dynamical SR variable). The conservative domain between represents spacetime. But according to our conception 4-space becomes a device for modelling the intricate assembly of network spins in terms of averaged continuous functions. The underlying transformations of unit distance should be applied not globally but case by real case.

xxi.) Superspin therefore has a projection as a distance, in exactly the limit where angular momentum and linear momentum become identical; but this is not a limit of *scale*. That is, it is not itself a distance scale. It is a *scale-free unit distance* that occurs as the rotational 4-momentum of *all* linear 3-momenta. The limits of this projection occur always as the scalar half-wave fundamental mode of any string segment. All linear projections of all segments transform relativistically as 4-space rotations which are changes of momenta or foldings at the vertices of the self-interacting network. These local changes are by definition the real intersections or real nodes at which real spins also change. There are only three real fundamental spin modes disclosed in these interactions: zero, one half, and one. Other internal virtual spins and external phonon spins occur as multiples of these modes. The spin-2 phonon, for example, always includes one real change of momentum involving an electron-electron, electron-positron or electron-photon event at one network vertex, and the included SR angle is the generator of *local* spacetime action invariance, whilst the induced 'gravitational' coupling represented by spin-2 also appears locally but is generated *globally* as one pole of a 4-rotational dipole transform of the spin-0 inflaton. So gravitation, instead of being a tensor function of a scalar energy, becomes a function of *vectorial **changes** of energy* (changes of momenta) and so is radically generally relativistic in the relations of 'particles'. The tensor becomes a vector gradient of these *discrete* vertices, and so models an emergent *statistical* distribution. Each vertical change is associated with a renormalisation of h or c by an incremental rotation of the superspin gauge, allowing 'gravitation' to be expressed as a dispersion of linear momenta through a 1-dimensional vacuum of discontinuously-varying 'refractivity', generating an intricate quantised 'curvature' (folding) in a fractal global dimension.

5. Superspin Interpretation of the Field

i.) When we try to understand spin in conventional QM the spin eigenstates are in a first approximation degenerate and commute with the energy eigenstate, the Coulomb force being spin independent. This degeneracy is removed when the electron is considered to be 'in a magnetic field' and the available states acquire different eigenvalues corresponding to opposite orientations 'in the magnetic field'. In our terms the two-valuedness of our objects is the doubling of the space of spin eigenstates, but the reason for the non-degeneracy in eigenvalues is less clear, as is the meaning of this condition called 'being in a magnetic field' itself, since the heuristic model we are exploring not only contains no classical current loops but also deprecates the reality of any continuuum of point potentials.

ii.) One is encouraged here by the fact that physics does not contain any really well-defined idea of what magnetic field *is* other than some phenomenological description of relative speeds and distances of 'moving charges'. If the field is just a convenient device to generalise calculations of the 'force' on an arbitrarily moving test charge, then it will obviously be possible to discuss magnetic forces solely in terms of the relative motions of charges. In Maxwellian theory this is difficult. But if classical electrodynamics is adjusted so that this is possible, what we get is exactly the special theory of relativity! Given Coulomb's law just about the whole of electromagnetic theory can be derived from SR. (Einstein [58] himself stated that SR grew directly from intuiting that a magnetic field was only an electric field in a moving frame.) The magnetic 'field' then is just a Lorentz-invariant transform of the Coulomb field for moving charges ('observers'), which has a special interest because, even though it is local, the force depends everywhere on the velocities of *all* charges. So what is the meaning of an atomic orbital's orientation, or an alignment of electron spins, 'in a magnetic field'?

iii.) Evidently its only practical meaning is a direction in relation to some specified drift of charges. In an example given by French [59] the drift velocity of charges in a typical wire carrying a 10 amp current would be barely perceptible to the eye (a couple of metres per hour!), yet for a test charge moving alongside the wire at the same drift velocity an unbelievably tiny relativistic Lorentz contraction of the inter-atomic distance of about 1 part in 10^{23} alters the positive/negative charge density in the wire sufficiently to produce a significant 'force' of magnetic 'attraction'. The magnetic field is entirely relativistic. From an SR point of view it would be more empirically transparent to say that a motion of some test charges, or a certain alignment of electron spin vectors, *is* some region of a magnetic 'field' rather than being 'in' a magnetic field. Thus an intimate association of spin-orbital magnetic moment with the structure of SR spacetime that I want to bring out is very natural. The extension to an association between *superspin* and (in effect) GR spacetime may not at first seem so natural!

iv.) A 'fundamental' value of this magnetic fraction *v/c* occurs as the spectroscopic *fine structure constant* (alpha ~ *v/c* ≅ 1/137), which can also be expressed in terms of several other combinations of 'fundamental constants'. One definition is that it is the electromagnetic coupling constant, whose smallness makes atoms 'large' and their electrons loosely bound, and makes it possible to calculate their behaviour in a non-relativistic approximation. In this treatment, alpha determines the magnitudes of the available orbital angular momenta and hence the Zeeman absorption lines. But it can be considered established that this ratio *v/c* is not a classical gyroscopic velocity, although *v/c* does represent a magnetic moment. In an illustration given by Eisenbud [60] the first of the two Δ0.01 Ängstrom position measurements required for even a rough specification of electron orbital velocity would lead to a momentum uncertainty equivalent to perhaps 1000 times the ionisation energy. Going on from what should be called the 'gross structure constant' to the line bifurcations of 'intrinsic spin' eigenstates leads to greater difficulty. What kind of a 'rotation' now remains? But from a network point of view the question is not: 'How far does an intuitive model of classical moments carry over into weird quantum particles?' but rather the opposite: 'How does this weird magnetic moment arise in an intuitive theory of linear objects?' Or, what turns the effective scalar field of equilibrium charge into the non-equilibrium vector field of electromagnetism? Or in still other words, how does Lorentz-invariance emerge out of a broken superspin symmetry?

v.) Under local measurements, each of our nonlocal objects has a basic two-valuedness of position which also entails a basic two-valuedness of spin, expressed at opposite nodes reciprocally. The simple symmetry group of rotation for this 'intrinsic spin' is *in general* broken for these local measurements in such a way that 'up/down' acquires an indefinite number of possible local orientations defined with respect to the local magnetic field. When the local magnetic field is weak its direction for electron spin generally is the direction defined by the total angular momentum vector which is the invariable axis of the atom, so intrinsic spin can be approached crudely *as if* it were a correction to the allowed orbital angular momentum eigenvalues, a small quantitative increment of the same kind. But this is not right. The orbital angular momentum eigenvalues, though integer quantised, are local dynamical variables that can have infinitely many measurement outcomes; they are *in some sense* energy states of local space rotations, even though the spectrum of possible states is not continuous. Even though a meaningful electron orbital velocity is unmeasurable in principle the relativistic ratio *v/c* does determine the orbital magnetic moment *as though* for a ballistic particle. But the intrinsic spin eigenvalue is *qualitatively* quite different in that it is fixed, and there is no way at all of representing it as a Lorentz-invariant rotation. The correct way of looking at it, therefore, is to say that this nonlocally intrinsic property called electron spin is carried over as a component into a more complicated group of rotations which emerges in the locally broken symmetry, but *it is not itself a local dynamical variable*.

vi.) To labour the point, the unanswered question is this: If intrinsic spin is not a local dynamical variable, that is to say if it does not transform with the symmetry group of SR; if it doesn't have a spectrum of eigenvalues in a magnetic field; if it is an imported constant action whose *direction alone* is set by the magnetic field; if all these are true, intrinsic spin cannot be an electrodynamical phenomenon except as it supervenes on electrodynamics in some limit. Given this, what then is it that removes the degeneracy of the doubled eigenstates in the first place? How can a fixed quantity be said to couple dynamically to a local field without coming *un*fixed and yet avoid violating energy conservation? The approach taken here is that the problem seems to be clarified if we propose that this is all back to front: *Direction is fundamentally quantised* in the structure of the network. Direction is not 'set by' the field; direction is rather the *real essence* of the quantisation condition. The imaginary 'field' is a projective medium useful in the mathematical treatment of discrete directions.

vii.) Intrinsic spin is therefore the more fundamental property, and does not belong inside SR. We propose that intrinsic spin is a glimpse of what *generates* SR. Contrary to what the relative scales of nested spectroscopic multiplets might superficially suggest, intrinsic spin is not a 'fine correction' to the relativistic orbital energy, any more than GR is a 'fine correction' to Newtonian gravity, or quantum theory is a 'fine correction' to classical mechanics. It opens a different window on nature. This perspective would explain the strangeness of how a vectorial component of a nonlocal statical constant can appear to be 'set' by a local magnetic field. The answer is that its direction *isn't* 'set' by the magnetic field; rather the magnetic field emerges as a local map of spin alignments and, through the spin-orbit coupling, atomic orbit alignments. In general 'the magnetic field' occurs as the breaking of the superspin symmetry, which remains imprinted in its local transform as a common limit of action underlying all projections of unit distance (i.e. all observer-specified relativistic times). The spin-orbit coupling does not arise in the first ('strong field') case which is equivalent to the angular momentum of our nonlocal torsion remaining hidden in the 'superspin field', i.e. as electron intrinsic spin. The projections of the superspin and the orbital spin vectors on the field are quite independent. Although this is called the strong field case what we are really seeing is not the *application* of a strong ordering to some weak, arbitrary states, but on the contrary the damping or *reducing away* of the Lorentz-invariant local spacetime order to reveal a strong spin-correlation order in its limit. The underlying symmetry breaks first to a spatially rudimentary, strong spin-correlation case, preserved in special domains such as EPR pairs. The emergent local symmetry is a spatially complicated, weak-spin case, the symmetry of electromagnetism which holds between the

$\sqrt{(2N)}$ nodes/origins which represent 'measurements' of electron states for N objects. Among sets of these electron states, considered as moving charges, there emerges a relativistic 'drift' of current whose 'magnetic' torque defines a collective rotational direction. From this point of view we can see that the 'orbital' angular momentum begins as a transform of a set of linear momenta, and its quantisation can be seen as a consequence of the fact that angular relations are not secondary selections made from some pre-existing field of all possible space-rotations; rather, angular relations are *assembled* out of linear elements (or in the folding and refolding of the string under the locality condition of its self-interaction, if we wish to put it this way). Intrinsic spin thus enters as a relativistic term, but it is not a special relativistic variable; it is a limit on locality but is not itself local; it is a determinant of magnetic field orientation rather than a response to it.

viii.) Now it is possible to say that insofar as spacetime is defined as the Lorentzian manifold of special relativity then it is dynamically constituted entirely by the 'magnetic field', because the electric field of a system of static like charges in equilibrium is *effectively* a scalar. 'Effectively' because a field in which a test charge placed at some position feels a directed force is formally a vector field; but this test imports tacitly the *non*-equilibrium dynamical transformation which is assumed for any real case, and the vectorial character of the field is emergent only in those 'placements of test charges' etc. which are actually electro*magnetic*. In an imaginary Coulomb field of undisturbed *like* charges in equilibrium there is by definition no preferred direction, no preferred observer frame and no concept of velocity, just a field of equidistant charges whose number on the surface of a spherical shell of radius r centred on any charge O goes up as r^2 whilst the strength of the force centred on O goes down like $1/r^2$, and it is only the relativistic dynamical transformations of the Coulomb force law associated with non-equilibrium motions that produce the magnetic vector field as the fraction v/c of the electric field, due directly to the constant finite speed of light. This gives us the flat Minkowski manifold of SR along with an electric field which is actually a dipole, so now it is a vector field with emergent relative scale. Relativistic electrodynamics is coemergent with the dipole character of the 'field'. The implication of our new view would be that this happens because the dipole is itself generated in the transformation of monopolar *super*charges (inflatons) to a magnetic vector field. This would allow us to explain 'positive' and 'negative' charges as phenomenological labels attached to local mappings of one nonlocal action which is itself a neutral scalar. The justification for this procedure is that it conforms to the emergence *in parallel* of a 'gravitational' dipole with positive and negative signs, placing the mass field in the same symmetry with the charge field.

ix.) It is not difficult to defend in casual terms the implication that spin is more general and more fundamental than SR spacetime. SR preserves the angular momentum of all rotations for all local observers as it preserves the action; but it does not itself give any account of the origin or significance of angular momentum. It is a description of electromagnetic rotational moments that *do* arise, but it does not say why there is such an interesting dynamical equilibrium in the first place. It is not an explanation of why the universe isn't describable as an homogeneous and isotropic scalar field of overall zero potential - or in other words, it is not a cosmological theory. Obviously it doesn't attempt to be such an explanation; it is only required to describe magnetic transformations of an electric dipole field of varying potentials without explaining where this dipole comes from. This limitation of its account of angular momentum in terms of the magnetic field is in fact explicit: It doesn't 'include gravity' - i.e., the electromagnetic field is spacetime with gravitational mass and inertia reduced away. However, a network model suggests that this dipole would be coemergent with SR space scale just as a gravitational/inflational dipole is coemergent with space scale. One certainly expects that positive and negative charges *should* unify cosmologically since they are relativistically transformable in the CPT mirror, and do indeed physically unify (as neutral 'charge', say as a photon, and in an extremal mass/charge limit) and it would be satisfactory that they should unify inside a theory which is also a theory of gravity and reconciles the dipole/monopole disparity of charge and mass. Our network model implies an electromagnetic charge dipole which is a relativistic transform emergent *with* the magnetic field and rooted in a *neutral monopole* inflationary 'field' which also gives rise to a mass-charge dipole. In both cases the local sign of the charge (a phenomenological label) would be nonlocally context-dependent and correlated with the emergence of metrical scale. This is why we do not in general encounter 'negative mass' (with the theoretical exception of particle-antiparticle pairs as indicated in *4.xiv*): Only an 'experiment' on a cosmically significant scale would need a theory in which *m* changes sign for macroscopic bodies.

x.) A negative scalar inflationary field of electrons would be indistinguishable from a positive scalar inflationary field of positrons. Unperturbed, this indiscernability would be an identity. The meaning of displaced equal and opposite charges is a relational meaning bound up with the meaning of scale. The relational meaning of scale is by definition not an absolute and must be an emergent meaning, and the selection rule must by definition be connected with the emergent spacial ordering. It is very natural therefore to suppose that a selection rule governing the emergent electrodynamical dipole is connected with the coemergent dipole of inflation/gravitation, which is considered fundamental to the spacial ordering of inertial mass-energy. In itself this 'unification' of electrodynamics with gravitation is just an obvious *desideratum*. But normally when considering the origin of inertia one looks to some variant of GR cosmology to supply the necessary negentropic ordering, and the result is a somewhat complicated redundancy of neo-classical fields, further textured by superposed quantum fluctuations, and then tweaked with global inflation, dark matter, dark energy and so on, not to mention unknown physics required to account for the cosmological constant problem and evidence of fractal galaxy distribution. By applying our nonlocal-object network model, however, we get the idea that an inflationary superspin which is *prior to* quantum electrodynamics offers the prospect of a tranformation of SR which captures the essential function of the conventional transformation SR $\rightarrow$ GR but which might give answers of a novel character to such questions as why so much of the mass of the universe is spinning, why gravitomagnetic forces arise, why the mass distribution looks self-similar, contradicting GR-based cosmological models [61], why these models do not elegantly represent the gravitational dynamics on galactic and cluster scales etc. (see *Parts 6 & 7*). The essence of the proposed duality of such a model with an effective field theory version of GR would be that the projection in 3-space of an orthogonal 4th-dimensional curvature between two points is cognate with a torsion in a null geodesic connecting them. Thus the Einstein stress tensor would be identified with the restoring potential of a broken superspin, and the string-segment would be represented as a geodesic line element of the projective 4-space surface.

xi.) As to what prospect there may be of turning such an idea into a useful formal theory, it is worth pointing out that since about 1860 there has existed the basis of a complete algebraic alternative to the now-familiar holomorphic spacetime of GR in the form of the Cayley-Klein construction of 'distance'. Cayley [62] showed that cross-ratios of linear ranges of points have an invariance under projective transformation which is analogous to that of Euclidean angles and distances. The cross-ratio of four points is crucially dependent on the order of the points, which defines a *sequence* of operations determining either a negative or a positive result, and the same applies to a pencil of rays projected from these points, which are said to be harmonically related when their cross-ratio is -1. Cayley defined distance between points on a line in terms of an equation of angular measure whose odd property is that for two points P and Q it yields a natural unit distance d(P,Q) corresponding to $\pi/2$ when the coordinates corresponding to P and Q, which may be p and q respectively, necessarily satisfy the equation $pq + 1 = 0$. (Notice that in the special case where P and Q coincide and the distance d(P,Q) is zero, $p = q$, and therefore since $pq = -1$ both p and q become imaginary.) Since Cayley's equation contains the term $pq + 1$ (equal to zero) as a numerator, the distance d(P,Q) becomes proportional to an angle whose cosine is constrained to be zero, and so the very strange situation emerges that *whatever* the coordinate separation of P and Q they are always at unit distance $\pi/2$. Cayley's equation may be proved to satisfy the expression $d(P,Q) + d(Q,R) = d(P,R)$, which is the common-sense conception of additive distance where (say) two half-metre intervals make one metre interval; but in Cayley's conception of "distance" *all* intervals become expressions of the *same* projective invariant.

xii.) What does Cayley's invariance theorem have to do with a model of gravitation based on the invariance of action among a network of linear nodal relations? The trigonometrical and geometrical formulae obtained for surfaces and higher figures on the basis of the Cayley-Klein definition of distance are exactly those obtained in the non-Euclidean geometries of so-called "curved space". It was Klein who followed this emerging trend, a trend which accelerated especially in Germany at this time owing to the work of Riemann. Cayley himself was not very inclined to take seriously the idea of the violation of Euclid's "parellel postulate" in curved space. And he may have been right. The most telling argument is, of course, that in the light of quantum theory the Riemann-Einstein programme *is known to be fundamentally flawed* in its assumption of a smooth spacetime. It is pertinent to observe that the European pursuit of a geometrical theory of invariance in a sense set the fashion for what finally emerged as Riemann's general analytic transformation. Without this legacy it is possible that the differential invariance that underlies the continuous transformations of fields, and which fell fully-formed into the lap of a relieved Einstein, might not so completely have overshadowed the algebraic invariance of Cayley. It is possible to speculate that a generalisation of the theory of relativity might then have taken a very different form.

xiii.) The implicit functional identity of the Cayley-Klein theorems and the new characterisation of space was explicitly set out by Felix Klein [63], but Cayley was well aware of this identity. Cayley had shown how to extend his definition from the line to the plane, or from the plane to the solid, by postulating arbitrary sections in the higher spaces of which his "coordinates" can be taken as projections in the lower. Interestingly, it happens that the whole of what we might call the space of the absolute or, with justice, the "Cayley space" of plane Euclidean geometry is a *complex* non-Euclidean space with real and imaginary forms: When the absolute is real the metrical formulae are exactly those obtained for Lobachevskian or hyperbolic geometry (open, negative-curvature, saddle-surface spaces), and when the absolute is imaginary the formulae are the same as those of elliptical geometry (closed, positive-curvature spaces, of which the spherical space of Einstein is a special case). And it is very interesting to see how the Euclidean case, in which space is open and flat, reappears from this *complex superposition* and cancellation of real-negative and imaginary-positive curvatures. The point is that whilst these abstractions may be technically useful they may be inessential. And if a network theory is true then *all* continuous manifolds become abstractions, not just those non-Euclidean forms that happen to offend the parallel postulate.

xiv.) This becomes clearer if we say that where Cayley held his absolute surfaces to be abstract when conceived in more than three dimensions, we hold them to be abstract when conceived in *less than* 10^{80} dimensions. That is to say, in geometrical terms "the line" may be taken as the Cayley absolute of "the point" (i.e., of the null signal line) and a figure in "the plane" is the absolute of "the line", just as the absolute of the solid is in turn a quadric surface, and so on. But none of these neo-Cartesian abstractions are *discovered elements* of the world at all; in geometry they are imposed structures, derived ultimately from analogy with structures in nature which are *emergent structures*. The actual underlying relations out of which they emerge (the quantum condition underlying an *effective* field theory of gravity) appear to respect a quite different definition of structure, a non-local projective structure of linear elements each of which is in effect the Cayley absolute of a *null* interval, and whose further projections define emergent spaces of 2, 3, 4 . . . *n* dimensions. We should regard these generalised geometrical structures as abstractions from merely topological relations and not as prefabricated matrices of coordinates. On the cosmological scale notions such as the "celestial sphere" and the "light horizon" convey rather vividly the impression of a bounded 3- or 4-space volume centred on the observer; but when we look closely at what such abstractions are built up on we see that they are used to generalise the *operation* of making projections of the null geodesics of specific photons according to certain rules. The portmanteau of these theoretically and observationally interdependent rules applied to the generality of all possible photon projections (or light rays) *is* spacetime. A topological procedure is generalised as a geometrical principle. This may be very convenient, but it may also be very misleading when it tempts us to construct a cosmology like a global history by joining an infinite number of possible points of measurement smoothly together by means of continuous non-Euclidean functions.

6. Reflections and connections

i.) The idea of a generalised nonlocal connectivity is not new, of course. It is as old as Newtonian gravity. It has been an issue in quantum theory almost since the theory was invented, and instead of being relegated to an n^{th}-order problem nonlocality has become ever-more central to foundational questions during the last hundred years, despite the overwhelming dominance of the local field paradigm. In the 1940s Wheeler and Feynman [65] proposed to reinvent classical field electrodynamics as an action-at-a-distance theory, with some success, invoking a back reaction from a future event by mixing advanced and retarded wave solutions of the Maxwell equations; however problems with quantisation and an arbitrary boundary condition led to it being abandoned. The absorber theory demotes the field to a book-keeping device to avoid infinities but there still is classical Maxwellian radiation. The electromagnetic field is still there; the difference appears to be that the Feynman-Wheeler field is entirely determined by the *particles* - it has no *independent* degrees of freedom and thus the electron charge does not get acted on 'by itself' in the form of these independent degrees of freedom of the field. Hence the infinities would be elided. But because this classical field is not quantised into photons one then has to explain the photoelectric effect, spontaneous light radiation of atoms, and so forth, in addition to the cosmological requirement that all emitted radiation eventually gets reabsorbed in a closed universe. All of these problems are effectively addressed, in principle, within the new ontology outlined here, which removes the infinite degrees of independent freedom of the field but retains the function of photons inside a quantisation condition that automatically produces the Wheeler-Feynman boundary condition. Later when introducing his mature spacetime representation Feynman [66] pointed out that the fundamental first-order interaction equation strictly speaking only applies to virtual quanta, but that it was possible to generalise to 'real' photons because in any closed system *all* quanta can be considered as virtual - that is, every emission and absorption takes place internally and is an unobserved component of some exterior sum. He pointed out the complete equivalence of his description with the conventional quantum description in such a case. This was an heuristic argument, but again the same boundary condition can be seen to be the essence of a network system whose closure is analogous to that of a black body radiation cavity. It is suggested that the superspin network can be considered as having implications for QM that are dual with those of the transactional interpretation developed by Cramer [67] on the basis of the Wheeler-Feynman theory - i.e., almost complete practical triviality - but that whereas in Cramer's view the string-like picture of absorber theory interconnections remains a phenomenological device, the superspin network is a genuinely new ontology that makes distinctive predictions (although so far merely qualitative) beyond quantum electrodynamics.

ii.) Chiefly these arise from the non-field interpretation, and since the currently most successful theory of gravitation is conspicuously a field theory we can expect some differences. In particular the emergence of 'attractive' Newtonian gravitational interactions from the form of a primarily repulsive potential confined to the network lattice means that although the theory would predict gravitational *radiation* it would not predict gravitational *waves*. Gravitational wave observations therefore become a negative test of the theory.

iii.) To be specific about the distinction: Consider a spacetime interval from the points of view of GR and network theory. First, consider a single half-wave interval or string-segment. (This is an abstraction for the purposes of argument from an inherently pluralistic theory, of course, not a real possibility.) There is what we can call a 'space amplitude', which is a standing wave amplitude orthogonal to the time vector, but whereas the vector is a relativistically-real interval carrying a time-varying frequency the space amplitude is *not* time-varying: It is the fundamental mode of the oscillator and has *no* frequency. Obviously the dimension of this amplitude is what we recognise as the spin polarisation plane (see *4.i., note 4, p.28*) and the rotation of this plane becomes equivalent to a curvature. Variations of this space amplitude (which has the same function as the phase speed c of a particle wave group with $v < c$) are *imaginary*. (They would correspond to an *'internal*' space geometry of a quantum of curvature, which, if real, would assume local analysability of a quantum of gravitation into a continuously varying potential. This seems unintelligible.) This amplitude is a scalar in terms of any single interval and only becomes "time-varying" as a half-cycle of a train of a number of such phase waves, i.e. in a phonon excitation mode. Such a wave train, in turn, becomes like the gravitational wave-group dispersion (i.e., becomes like an 'object') of a wave of higher phase speed, and so on, until ultimately all gravitational wave-groups (all 'objects') are seen as dispersions of the standing-wave phase of all space. But this variation of the space amplitude is not a real time-variation leading to a real space frequency, i.e. to a measurable frequency, because although the space amplitude varies as a function of a global 'time', this global variable is in fact space-like and the time-variation is imaginary. This variation in a scalar 'time' is not an observable. The scalar limit of all *real* times for any given interval is of course c. Thus the change in distance will always be inversely proportional to a change in the speed of light by which it is cancelled out. (This is equivalent to saying that c is a constant of floating norm. See *4.vii, note 7, p.33.*)

iv.) In GR and network theory the observables must of course be the same. But GR has a time-variation of imaginary space-amplitudes occurring *within* interval (that is, *between* observables), and a quantum theory of GR-gravity will naturally be a field theory of bosonic gravitons which then has to be coupled to arbitrary masses. That is, whereas the root principle of a quantum theory of radiation is that one boson goes wholly and uniquely to one fermion (i.e., in QED, one photon goes to one electron), the energy of gravitational wave radiation has to spread omnidirectionally and subsists (as problemmatical 'quanta of curvature') throughout space. According to GR an indefinitely large space field containing only two indefinitely small oscillating masses is filled with gravitational waves of indefinitely small amplitude at the frequency of oscillation, even though no test particle exists by which these waves might ever be detected or by which the relative motions of the masses might be otherwise gauged. The very meaning of 'mass' in such conditions is obscure. A real GR space wavefront is thus conceptually very difficult. But in a network theory the existence of a space wavefront which is an unobservable locus could have *only* an imaginary meaning. There is no real smooth substrate. Instead of a continuous space we have the line elements of a fractal boundary, and this 10^{80}-dimensional boundary becomes the *origin* of the principle that only actions generated in the real relations of observables have meaning. Thus, instead of a time-variation of imaginary space-amplitudes occurring *between* observables as in GR, network theory has a space-variation of imaginary time-amplitudes occurring *as* observables, i.e., as pairs of states bounding intervallic string-segments; and the transformation algorithm for mapping an ensemble of intervals one onto another is special relativity, which gives us the electrodynamics of moving charges in the context of network quantisation.

v.) If LIGO and its sisters fail to observe gravitational waves this would be consistent with expectation, because the result of this space variation, with observables exclusively at all wave-nodes and intervals of quantised action carrying time-varying frequencies, whose transformations under the Lorentz group represent electric and magnetic potentials, is just what we already call quantum electrodynamics. One vivid (if ultimately very misleading) way of thinking about this is to say that gravitational wave radiation is ominpresent in matter but that its compression waves are always damped to extinction by induced opposite displacements due to the varying effective norms of electrodynamical constants. Evidently this would be equivalent to identifying photons as quanta of "curvature", and renormalisation in QED could then be seen as an accommodation of its invariance group to the effects of gravity. As mentioned, this is not in the end the most helpful point of view, but it expresses the idea that we ought not to expect measurable longitudinal space distortions over the optical path of even the longest laser interferometer.

vi.) Gravitational radiation, like any photon, will be invisible 'inside' any interval. Both become 'visible' only as some relation of charges. Network gravitational radiation will therefore be measurable as a displacement of mass. But mass radiation will not occur by a mass-charge coupling to a space field in a network theory, where there is neither a constant scalar charge nor a real space field. It will not propagate locally. It will dissipate nonlocally through the equilibrations of the whole network self-interaction, ultimately therefore being the origin of itself. Other than in this global metrical adjustment it appears only in a series or ensemble of intervals which is both the network analogue of a gravitational "wave train" and a series or ensemble of network "particles" - a supersymmetric phonon excitation, analysable into fermions and their exchange-force bosons according to how the odd/even spin rule applies over a given number of half-wavelengths. And because this radiation is not a local smooth field but a nonlocal fractal boundary we obviously don't expect space coherence in the form of a plane wave front: The cosmic gravitational radiation density is not a locus of disturbances in phase travelling in empty space, but rather tracks the cosmic mass-energy density, because it is simply the distribution of all "particles". In this sense one can say, picturesquely, that an inert gravitational wave detector *is already* gravitational radiation. Indeed the entire universe *is* the gravitational radiation from the Big Bang.

vii.) However the sensitivity of current-generation *G* wave experiments is extremely low. With expectation so close to zero for a positive outcome it may be difficult to demonstrate a negative. Is there any other possibility of an experimental check on G wave radiation? One controversial possibility is that of using a superconductor as a gravitational wave transducer. Network theory obviously predicts that this will not work. This may be a distinctive prediction, *if* - as is claimed - it is not clear that conventional field theory contains a convincing reason why it should not work.

viii.) Chiao [72] proposes that superconductors will act as transducers of gravitational and electromagnetic waves and that the gravitomagnetic radiation field should be expelled from a superconductor just like the electromagnetic field. Essentially this says that the dynamical component of Einstein's spacetime - i.e., not the "static charge" (mass) but the relativistic effects due to moving electron masses - is driven out, in such a way that the superconductor surface behaves like a plane magic mirror which reflects incident electromagnetic waves as gravitational waves with 25% efficiency. Sceptical physicists claim that a strong coupling between gravitational and electromagnetic waves in superconductors would already have been seen. [73] However Chiao proposes a simple experiment in which an electromagnetic wave incident on the surface of superconductor-1 should be transduced into a gravitational wave re-emitted towards superconductor-2 where it is transduced back into an electromagnetic wave and detected. If both "transducers" are isolated in Faraday cages then detection of an output from superconductor-2 signifies transmission of gravitational wave radiation.

ix.) There are no gravitational waves in our construction, and so the network prediction has to be that it will not work, because the "field coupling" is merely theoretical. The analogy between the electromagnetic field model and the gravitational field model appears pregnant because it discovers the approach to an identity between gravitation and electromagnetism in the low-temperature quantum limit. Expulsion of the dynamical gravitomagnetic 'field' means that the GR symmetry describing the relativistic relations of macroscopic mass charges is 'broken' in the superconductor and the bonding of 'repulsive' Cooper-pairs represents the identity of electrostatic charge and gravitostatic charge (mass) realised in the approach to thermal zero. This bond is equivalent to the vanishing (a false vacuum condition) of a static *effective* gravitoelectric field in the direction of the current as measured in the inertial frame of 'an electron'. The network analogue of 'gravitational radiation' will be simply the total fermionic emission of a system, which plays no part here, since an incident energy sufficient to stimulate significant emission would presumably turn superconductor-1 into a 'transducer' at the cost of destroying the superconductivity, and so would merely demonstrate the photoelectric effect.

x.) However this does not mean that there is no gravitomagnetic/electromagnetic coupling - far from it. It just means that its form is different. Chiao's direct coupling interaction Hamiltonian for superconducting Cooper pairs contains no length scale of course and is independent of the gravitational constant. It shows a coupling between electromagnetic and gravitational 'radiation' mediated by nonlocally-correlated pairs of electrons, with a coupling constant for the interaction equal to twice the electron charge. In the absence of a classical manifold our model does not support concentric gravitational waves, but it implies that precisely this kind of scale-free nonlocal 'transducer' - of which a Cooper condensate is one extremal case - *is ubiquitous at all temperatures*, but that it is precisely the ubiquity of gravitomagnetic 'transduction' which (if we wish to look at it like this) destroys the nonlocal correlation of generalised spin supersymmetry. If there were no such transduction all particles would be perfectly spin-correlated in a zero-energy false vacuum state incapable of thermodynamic work, all cosmic temperatures would be converted to gravitational heat, and (in classical-continuum terms) electromagnetic and gravitomagnetic vector forces would vanish to a scalar field. Thus, such transduction appears as the 'origin' of electromagnetic forces. As already pointed out (*6.x* above), we can express this in a picturesque way by saying that quantum electrodynamical phenomena suppress gravitational wave radiation. In fact we can say that quantum electrodynamical phenomena in effect *contain* gravitational radiation (which in a given case will be the rate of all fermionic losses from a system).

xi.) A further negative experimental prediction is possible in the area of sparticles. As re-emphasised in *6.ix* a network theory would enjoy a radical dynamical supersymmetry. There is no need to rehearse here the rationale for this claim; suffice to say that one would not expect the discovery of a discrete class of supersymmetric partner particles. This is consistent with the failure so far of accelerator experiments to detect sparticles outwith a narrowing mass regime at the high end of theoretical expectations.

xii.) It has also been pointed out (see in particular *2.iii. 4.viii & 4.xi*) that the theory would not indicate a need for a massive Higgs boson. Here again it is in conflict with predictions of the standard model that lie just outside the range of observations. This may not be undesirable given that the separation of mass and gravitation implied by the Higgs mechanism is at least inelegant and that some experimental doubts about the existence of the Higgs have been expressed [74]. Network modes can be identified analogous to the mass-donating function of Higgs particles, but these are not any truly distinct modes of the string, they are simply the fundamental modes of all spin pairs and as such are coterminal with the same nonlocal objects (string segments) otherwise identified as electrodynamical elements or gravitational elements. This exhaustive supersymmetry means that the mass-donating particle mode is identically the gravitational particle mode, a satisfying and rational economy lacking in the standard model.

xiii.) Consoli and Stevenson [75] and Consoli and Siringo [76] have explored a model in which an equivalent 'Higgs' particle occurs as a long-wavelength phonon excitation of a Bose-Einstein phion condensate. Consoli and Stevenson point out that in terms of such a mechanism it becomes possible to reconsider the Higgs field as candidate for the 'inflaton' scalar field of inflationary cosmology and argue that it improves earlier suggestions [77, 78, 79] that Einstein gravity could emerge from spontaneous symmetry-breaking. The gravitational constant would then be the vacuum expectation value of the scalar field. Consoli and Siringo further suggest how Newtonian gravitation may arise in a spontaneous symmetry-breaking phase transition from the symmetric phase of the phion condensate and remark that such a nonlocal theory, in which gravitational force has to be considered an effectively instantaneous long-wave excitation ($10^{17}c$) is needed for a realisation of the equivalence principle (see *2.x.* above). They suggest that such a description of gravity would turn out to be the same as a Feynman-Wheeler theory with nonlocal 'strings' and that Einstein gravity could be recovered as a weak-field effective theory generated by the underyling quantum theory. Further they point out that such a theory could address evidence of self-similar cosmic structure and might help resolve the dark matter problem. Certain resonances between the above point of view and the present thesis will be obvious to the reader. As mentioned in the *Introduction*, it is suggested that the present scale-free network concept represents a sketch of a non-perturbative non-field approach which may be dual with the underlying nonlocal field theory in their model.

xiv.) To recap this point: It has been suggested that the unbroken or 'unfolded' superspin phase of the network string is an inflationary mode. When folded on itself the scale-free repulsion gives rise to an 'attractive' short-range nonlinear inflaton self-coupling from the *form* of the folding. This form is emergent as follows: The string is the background-independent vacuum; its folding is cognate with a stepwise renormalisation of the vacuum gauge at each local node generated in the network of its self-interaction. The norm of c thus varies incrementally like the dispersion group velocity of the inflaton phase, which we can say is broken 'because' of a torsion in the string whose restoring potential becomes dual with a quantised 'curvature' in an effective field theory. We make superspin normative, which is analogous to setting as constant the 'specific rotation' of a gravitomagneto-optical 'Faraday effect' from which we derive a phenomenological factor h as the numerator of an imaginary angular momentum. The negative restoring potential of this super-rotation is a torsion in the photon linear polarisation plane which increases the space of quantum basis states for the dynamically-supersymmetric electron doublet. A nonrelativistic (i.e. nonlocal) superspin wave function would be degenerate in a pair of symmetric position states, a degeneracy preserved only in EPR-type correlations. In general the broken superspin symmetry expresses as a Lorentz-invariant transform, to a linear momentum, of an emergently real angular momentum, h/π, halved and quartered in the first and third partials of the inflaton. Thus a nonlinear self-coupling of scalar inflatons transforms spin-0 to an *internal* spin-1 coupling which can also be represented as dual with an induced attraction from a higher order phonon mode of spin-2.

xv.) A qualitative positive experimental prediction may be made with respect to gravitational anisotropy. In a network theory mass becomes a derivative product of the global distribution of momentum, dependent on the *form* of the distribution as measured in spherical coordinates locally at a point of measurement (and also on the *scale* of the interval between any two such points of measurement, which nonlocal dependency produces a scale-variant cosmic dipole responsible for small-scale mass attraction in the context of accelerating large-scale mass repulsion, a scenario with possible application to 'dark matter' and 'dark energy' models). It is possible that in supercooled experimental conditions certain materials may be reduced to a 'low'-energy dynamical equilibrium which is the network false vacuum state, in which they are rendered sensitive to an anisotropy in the global distribution of mass-energy. We can imagine that the local electrodynamical constraint reduces away at thermal zero, not to nothing but to *a point of dual phase* at which the underlying global constraint will begin to dominate. With a superconducting solid the natural dual point will not be reached; it may only be approximated by one dispersed phase of the material - conduction band electrons - which can be thought of as occupying a much higher false vacuum state due to the constraint of the crystalline atomic structure. But a gas of 'free particles' might exhibit instability at the point of dual phase due to a minute asymmetry in the global 'gravitational' constraint that is usually thermally masked. It is suggested that so-called 'bosenova' disruptions in Bose-Einstein condensates, which are not presently understood in terms of the well-developed standard theory of BECs and are believed by Weiman and some other workers in the field to require new physics [81, 82], could indicate such an effect due to the condensate being nudged off the false vacuum.

xvi.) If the particles in a nanokelvin Bose-Einstein condensate (BEC) are already thermalized as close to their lowest average energy per particle as the experimental regime allows, then the only way of shedding more thermal energy is by the BEC shedding some of its population. Where all particles were previously held in a false vacuum state by the local constraint at a temperature just a few billionths of a degree above the zero-point of thermal energy, now some will begin to experience the space-asymmetry of the global constraint dominating. In other words, particles in different regions of the BEC will begin to have 'weight' in various directions, arbitrarily with respect to the field-map of terrestrial gravity, and will 'fall' explosively out of the BEC with a range of kinetic energies far higher than any possible latent internal energy of the zero-point BEC. This is the non-local energy of the global constraint, the network 'vacuum potential'. Adjustment completed, a stabilised remnant of the BEC would then survive at the centre of an expanding cloud of debris. According to a network theory the gravitational radiation of a system is simply the sum of all fermionic particle emissions from the system. The energy of this radiated debris is neither thermal nor electromagnetic but represents the energy of the space configuration of the BEC at the zeroes of both. It represents the energy of a phase transition in the inflationary 'vacuum' constraint that donates the local mass energy of the BEC. To put it most dramatically, the 'bosenova' could be seen as pure gravitational radiation from a gravitational collapse in the laboratory. [85]

xvii.) Over the years a scatter of different values of G has been obtained in different laboratories around the world without a clear understanding of why the error-bars are so wide. Indeed Mbelek and Lachieze-Ray [86] have recently argued that although the errors are decreasing the values are not converging, so that the most accurate terrestrial measurements of G presently differ by ten times the intrinsic error. (Their suggestion is an unsuspected coupling between gravity and the earth's variable magnetic field; *vide supra* note 23, p.57.) And there is controversial direct experimental evidence of gravitational anisotropy. According to experiments carried out by Gershteyn *et al*. [87] the value of G varies with spatial *orientation* by at least 0.054%. If confirmed this would be extremely difficult to reconcile with existing gravitational theory. In a network theory as in conventional smooth-field cosmology the small deviations from uniformity in the gravitational energy density of the universe close to the 'last scattering surface' will be coupled to the mature cosmic matter architecture. But this coupling does not represent the time-evolution of an homogeneous average matter density from the 'early universe' to galaxies, and so is radically different from Machian interpretations of general relativity, where inertial mass is due to coupling with a local gravitational field. With $1/r^2$ field gravitation, distance variation would overwhelmingly dominate angular variation in any roughly isotropic cosmic mass distribution. But in a network theory the spacetime surface becomes a fractal boundary on which there is no average matter density and no real global distance scale; $1/r^2$ gravity is an emergent statistic; and local inertial mass becomes sensitive to angular variation in the cosmic particle distribution. The scale-free temperature fluctuations of the CMB as mapped by COBE/Boomerang/CBI etc. are then seen as shadowing just one component isolated in the limit of a *time-free* sky map (i.e., *radically* scale-free) which will be dominated by the density fluctuations due to the galaxy distribution. The fundamental network quantisation condition, prior to scale, is quantisation of *direction* and it is this complete nonlocal mapping from any given here-and-now which specifies - independently of radial distance scale - a local gravitational/inertial constraint whose departure from isotropy will be proportional to a varying angular node density on the celestial sphere.

xviii.) The COBE temperature fluctuation in the microwave background is 5.5×10^{-6}, which insofar as it maps a nascent background fermion density would be a theoretical minimum degree of network gravitational anisotropy here-and-now. The dominant contribution would be from the much coarser fluctuations summed over in the galaxy distribution. So the observed anisotropy would be expected to reflect the total matter distribution on the sky (independently of radial distance scale) with 5.5×10^{-6} as the bottom of a range of variation equal to the range of values of the anisotropy of the cosmic fermion distribution at all epochs. If an increasing degree of 'roughness' due to gravitational accretion is assumed to be proportional to the 'age' of the epoch, then the dominant contribution to the characteristic gravitational/inertial anisotropy of a test system here-and-now might be expected to be of the order of 100 times that due to 'ancient' structures with the roughness of the CMB, or about 10^{-4}. This expectation is not inconsistent with a claimed experimental minimum anisotropy of 5.4×10^{-4}.

7. Cosmological implications

i.) To sum up, the context for interpreting spin according to our heuristic proposal appears to be roughly this: The two-valuedness of intrinsic spin is a theoretical and experimental requirement. But the ontological connotation of 'spin' is less important than the two-valuedness which it stands for in the formalism. Indeed as mentioned in paragraph *1.ii,* there is *no* sensible fraction of *c* which can be set as the peripheral velocity of a spinning electron that would account for the required energy in terms of angular momentum. This is true if an electron is any smaller than the Compton wavelength, which is already six orders of magnitude larger than the limit allowed by the scattering data, at which radius the peripheral rotation would have to be much greater than the speed of light. And if an electron were truly a point particle, then the spin velocity v/c would of course become infinite. Yet spin angular momentum is inevitably bound up with the notion of metrical extension. As long as electrons are regarded as point particles in absolute space the original Schrodinger equation suffices. The relativistic Dirac spinor represents a departure from this view which remains problematic in terms of field theory.

ii.) To elide these difficulties and to embrace fully the context-dependency and wave-function symmetry of spin observables we propose to give up the particle/field representation in favour of a network of nonlocal linear objects. Under local measurements, each nonlocal object has a basic two-valuedness of position which also entails a basic two-valuedness of electron spin, expressed at opposite nodes reciprocally. It is conventional that a few pairs may preserve a singlet state of spin in a specialised nonlocal EPR symmetry, but according to our generalised symmetry *all* pairs can *always* be thought of as preserving a singlet state of *superspin*. Superspin is supposed to be carried as a 'super-rotation' of the plane of polarisation of a (linear polarised) photon. The photon itself 'sees' the restored superspin symmetry normalised (in null proper time) to that of a spin-zero scalar 'particle' and is blind to an imaginary torsion which it carries over into the mass relations of a pair of spin-half leptons as a spin-one electrodynamical symmetry. The emergence of the local-relativistic electrodynamical symmetry is to be identified with the spontaneous breaking of nonlocal superspin symmetry in the network. In this emergent local network each point of measurement of an electron can be seen as the origin of N complex radius vectors, each of which has some probability of being the photon vector which a measurement will elicit as being 'the electron spin axis'. Where the super-rotation of the photon (linear) polarisation plane inverts through π at the measurement node, *radial direction* determines which of two reciprocal spin vectors is 'measured' at the node at any 'instant' on a given radius vector, whilst the same binary choice is available on an indefinite number of radial orientations corresponding to an indefinite number of other photon vectors. The outcome of a measurement (for an electron) will be equivalent to determining a single active channel in this nexus (larger compound spins being vector sums of a number of such channels), and crudely speaking we can liken the electromagnetic coupling rate of 1/137 to a probability that any one channel will be (as it were) 'illuminated' at any given 'instant', the further implication being that if the unitary superposition of these active channels were not reduced by a perturbation such as a 'measurement' they would correspond to *virtual photon* states. (Of course, by definition of an electron as a 'permanent' entity, we have to say that they are *continually* being reduced by such 'measurement') As such they, and the indefinite number of similar electron/photon couplings to which they are *nonlocally* coupled throughout the cosmic network, represent what in QED becomes the *self energy* of the electron concerned. However, in the absence of a continuous Lorentzian local manifold of point position states this is a 'self-energy' that can go to infinity only in a universe containing an infinite number of 'particles', and its theoretical cancellation by 'renormalisation' can be seen to be a reflection of an actual process enjoined by the *scalar gauge renormalisation* that follows from self-consistency constraints of the cosmic string self-interaction - see *2. xvii.* above. (And the continual reduction of virtual states by 'measurement' is just the instant-by-instant actualisation of this self-consistency in the form of 'an electron'.)

iii.) Such a network ontology would have general implications for problems in cosmology, and one can immediately point to the areas of flatness and homogeneity and the cosmological constant. Here there is the prospect of an alternative perspective to that emerging from spin-networks and loop quantum gravity. There is also the remote prospect of an interpretation of anomalous galactic mass-to-light ratios within a general deductive theory. I'd like to close with a short discussion of these points.

iv.) Loop gravity claims to be background-independent but seems not to escape the problems of continuity. That is, unlike string/M-theory and traditional perturbative quantum gravity it does not split the GR manifold into a background metric and a superimposed quantum field. In this sense it is *fixed* background-independent. But it is quite conservative in that it takes the classical GR manifold as a given physical foundation and then follows the traditional route of quantising the formulae for classical observables. The loop representation carries spins around little loops to turn continuous GR spacetime into a Planck-scale spin network with something like 10^{180} nodes or vertices, a foam-like lattice down at 10^{-33}cm with a recurring elementary geometry, perhaps tetrahedral. It therefore does have a GR dynamical spacetime background with a smooth surface topology on moderate scales. The justification for this procedure is obviously that GR is a good theory. But if GR is an *effective* theory, not a structurally perfect theory, one naturally asks whether this procedure may import some structural imperfection.

v.) And so it does. The flat-Euclidean GR spacetime from which this process begins is known to be a hugely improbable outcome of an unnatural relation between inflationary fine-tuning and a mysterious cancellation of an enormous vacuum energy. It would be nice if a proper understanding of spacetime turned this unnatural relation into a natural one. But having generated something discrete which looks 'for all practical purposes' (FAPP) like smooth spacetime, loop gravity then discovers (not surprisingly, one might suggest) that its representation is altogether too efficient in that its Euclidean flatness remains colossally improbable. Smolin [88] estimates a probability in the region of 10^{-81}.

vi.) Consider the problematical concept of the position of an electron 'inside' the spatial volume of a single atom: Can it be the correct approach to import a scaled-down analogue of classical spacetime, which is to appear flat-Euclidean on the scale of an electron, and then to derive this appearance of an improbable continuuum condition from a matrix of 10^{75} spin-network nodes in an equally improbable state? Cosmic spacetime is then to be a tissue of such appearances stitched together, meaning that a number of nodes equal to some 10^{19} times the cosmic fermion number (about 10^{99}) is hidden inside every cubic centimeter of space. And if we think about this we can see that this huge quantity of hidden information exists essentially in order that loop gravity theory can import into each atom or each cubic centimeter the Trojan Horse of flat Euclidean space - an embarrassment of riches indeed, since this brings with it the even vaster disparity (10^{120}) of the unnaturally-cancelled cosmological constant. This seems especially redundant when we reflect that even on atomic scales forces are in principle unobservable.

vii.) This is to re-echo the problems of microcosmic quantum theory in a cosmic arena. As Feynman complained, 'How can all that be going on in that tiny space? Why should it take an infinite amount of logic to figure out what one tiny piece of space/time is going to do?' [89] The answer is not to simulate *un*measurable continuity at any scale at all, but to accept that measurable *dis*continuity *is* scale. A loop gravity spin network has a vast number of vertices, each connecting just a handful of edges, these distributed completely independently of observable changes of particle momenta. On the other hand our net divides that number of vertices by fully 10^{140}, but allows the tiny proportion remaining (10^{40}) to each be intersected by 10^{40} edges. There are of course exactly the same number of points of measurement in our network space, since a measurement always lives on an observed transfer of momentum. There is the same amount of information. But a loop gravity net has a huge number of redundant nodes that never become points of measurement, and those that do are themselves information-poor; whereas each of our points is information-rich and no point is ever redundant. The difference is between a FAPP local smooth continuum governed by global constants and a nonlocal network structure coemergent with local FAPP constants.

viii.) There can be no fuller specification of the position of any real observable than the set of its angular relations to all possible real observers. One doesn't need a continuum for this where the number of possible real observers is finite. If instead one looks for a procedure of 'joining the dots' in the most direct and exhaustive possible way, what one gets is not some clumsier analogue of continuous non-Euclidean spacetime but a different kind of structure entirely, a scale-free fractal architecture that is more like a tensegrity structure than anything else. A tensegrity structure is a dynamical equilibrium of compression struts and tension wires, a 'force-transmitting network' analogous to the model of the cell cytoskeleton proposed by Ingber [90, 91, 92] in which mechanical stresses on a web of protein filaments and microtubules transmit information to the nucleus much faster than chemical diffusion rates and might help to explain adaptive cell shapes, programmed cell death and tumour division. Physically, the analogues of compression struts and tension filaments would be the scale-dependent self-dual functionality of 'inflation' and 'deflation', operating nonlocally to generate resultant local 'mechanical stresses' on the segments of the network in the form of spacetime and electrodynamical forces. *Ex hypothesi*, in the self-interaction of the string there is a spontaneous symmetry breaking to the local spacetime phase of this network, and intrinsic spin, which supersymmetrically carries the hidden superspin, occurs as an embodiment of this breaking. It is therefore interesting that a tensegrity structure's characteristic resistance to developing torque under shear could be conversely expressed as a capacity to transmit torque, perhaps explaining the efficiency of spacetime as a rotational energy 'sink' *via* gravitational contraction (see *4.xviii.*).

ix.) Which leads to the questions of large scale cosmic structure and gravitational dynamics. The cosmic validity of the isotropy and homogeneity assumptions built into GR is presently under increasingly critical examination. Several rather strong arguments are listed by Baryshev [93], for example the problem that the linear Hubble relation is now known to apply on relatively short scales far smaller than any possible homogeneity distance that may exist, deep within the region where fractal structure is observationally well established [94]. The force of the traditional argument pointing to the consistency of a linear Hubble constant with the cosmological homogeneity principle has thus vanished, and the origin of a linear Hubble flow inside a complicated fractal velocity field becomes interesting. It is also the case, as pointed out by Baryshev, that global gravitational energy conservation is a problem in an FRW model on at least two counts: the loss of radiation mass during expansion [95]; and violation of the 1st law of thermodynamics by the zero pressure gradient of homogeneous unbounded space [96]. Penrose [97] is intrigued by the nonlocal character of gravitational energy in GR (and would like to use this uncertainty to somehow interpret state vector collapse in QM; see *Part 4*). And a canonical quantisation of GR which tackles the fine-tuning of primordial inflation and the vacuum energy in an accelerating universe seems as far off as an explanation of the origin of inertia in a local field theory of gravity.

x.) Several attempts have been made to avoid the need for another theoretically awkward plug-in - 'dark matter' - by modifying gravitational dynamics. The MOND scheme due to Milgrom [98] has proved empirically very successful indeed, and the objection that MOND is theoretically arbitrary may be true but doesn't carry conviction in view of the fact that many lines of argument seem to lead to the conclusion that GR is a limit-case effective theory. In the 1930s discrepancies between observed and dynamically estimated mass were noted in the solar neighborhood by Oort [99] and in galaxy clusters by Zwicky [100], and analogous discrepancies in the rotation curves of many galaxies were confirmed in detail in the '70s and 80s [101]. Modified gravity theories in which the Newtonian law breaks down above distances on the order of 10kpc failed because some compact galaxies need corrections below this scale, whilst others need none far above it. It became obvious that a systematic modification of a pure distance law alone would not work, hence the idea of dark matter. However MOND scores by choosing an acceleration parameter instead of a distance parameter and so doesn't demand naive scale relationships that aren't observed. Almost all of the effects predicted by MOND *are* observed, although where the constant of acceleration comes from which supplies the cut-off in the transition to Newtonian dynamics is as yet unclear [102].

xi.) The upshot of the last two paragraphs seems to be that a new kind of gravitational dynamics is required which goes over approximately in some limit to an effective field theory producing GR and the MOND low-acceleration parameter, whilst emerging from an essentially fractal underlying quantum theory. It is possible that such a theory could look like a scale-free network theory of the present type, for several reasons. Firstly, we expect *relative* inertial mass to be nonlocally determined according to a scale factor only in the sense that *relative scale is itself determined nonlocally*, and this appears to give the necessary connection between spacetime geometry and inertia. In other words, the component of inflationary 'force' which represents the scale dependency of the relation between two inertial masses is the same component responsible for the local geometry of the effective metric between them, and this spacetime slope according to GR *is* the acceleration due to gravity. Mass and scale are codetermined by inflation (or from a different point of view are codeterminants *of* gravitation), so that there should be a covariant coupling between scale and mass which is not constant but whose underlying rate itself varies inversely with the emergent scale according to a cosmical constant which has the dimensions of an acceleration. Empirically there is such an acceleration called the Hubble constant, H_o, which turns out to be related in a simple way to the scale-free MOND acceleration parameter, α_o, as $\alpha_o \approx H_o c$; and if it is true (as suggested in *7.ix.* above) that H_o is a robust constant of a fractal galaxy distribution that has no homogeneity scale, then the suggestion is strong that these may be co-derivative limit values of the same parameter, related by a global constant - the speed of light - in an effective local field model that is driven by an underlying nonlocal, fractal, quantum theory in which *c* is a network renormalisation parameter c_{norm} (see *4.vii*). In the effective field *c* becomes a constant of all scales so that energy conservation requires *m* to be a constant of all scales. But on the network $E = m_{norm} c_{norm}^2$, where the total real energy is automatically self-constrained (see, e.g.: *4.ii; 4.vii. note 10*), and effective mass varies with effective scale - i.e., with the gravitational deformation of route-dependent time, or equivalently with the acceleration. (From a field-theoretical point of view this renormalisation of *m* can be treated as an adaptation to the fact [*7.ix above*] that in FRW models gravitational energy is *not* properly conserved.)

xii.) I should emphasise again that because this variation in norm arises as a property of the network 'dispersion' (renorming at each self-interaction of the string, as a constant of successive segments or 'particle pairs') it does not translate into a direct proportionality with distance scale. The emergent global variation will be a *statistical* resultant of these nonlocal component 'forces', which will show a systematic variation only in rough *in*direct proportion to global distance scale. So although it will be a qualitative prediction of our model that as effective inertial mass changes with the look-back time so the effective values of 'fundamental constants' will change (see *7.xvi.* below) this is quite different from postulating secular temporal variations in a field theory based on an homogeneous physics. The statistical resultant will be like the sum over a complicated effective field of local variations converging in the scalar limit of the light horizon, which convergence produces the fractal analogue of an homogeneity scale. The homogeneity is not physically fundamental but instead emerges from a quantisation condition which is radically scale-free and radically fractal.

xiii.) The coherent nonlocal symmetry of the network is spontaneously broken in its own self-interaction, and in the emergent local universe of 10^{80} EPR-*un*correlated fermions each observation of a 'particle' (every vertical change of momentum) represents only one of the 10^{40} different values of *m* appropriate to its pairings, *via* a hidden superspin symmetry, with all other 'particles'. Of necessity those pairings where the dynamics of the relation have historically been inferrable from direct kinematic measurements have been within the 'laboratory' of the solar system, which imposes a practical limit of numerical scale. A measurement of inertial mass which indexes (say) 10^{20} pairings of a particle in this 'laboratory' still leaves out of account 10^{20} *other* inertial masses which that same particle (node) possesses in respect of other pairings outwith the accessible 'laboratory'. The variable degree of spatial anisotropy of this quantity called inertia (gravity) in the frame of the 'laboratory' is modelled quite well by Newton's $1/r^2$ law. But looking beyond that frame we find that the law is contingent primarily on this ratio of *numerical* scale, which secondarily expresses as a renormalising metrical scale deformed by gravitational acceleration.

xiv.) This contingency is more complicated than simply altering some distance parameter for an attractive force on a smooth background because this 'background' can itself only be introduced as a dynamical variable. This happens in GR. But a network theory would eschew the background altogether, the difference being that mass itself now becomes a dynamical variable. The local limit in which the Newtonian law breaks down is always a false vacuum state supported on the internal inflationary pressure of a domain of nodes - an aggregate mass - and for small aggregates this internal vacuum energy operates with an opposite sign to the external constraint coming from the cosmic environment. For much more extended aggregates the scale factor associated with the external constraint begins to introduce a component of the *same* sign, increasing expansion velocity in the observable limit of the cosmic light horizon. (This global horizon then represents a phase change beyond which internal and external vacuum contributions operate wholly with the same sign for an aggregation of 10^{40} nodes.) Systems of varying node number will encounter equivalent phase transitions at varying local scales because scale and mass are co-emergent dipole representations of the nonlocal network monopole. That is, for each *numerical* scale of aggregation the contribution of the external vacuum constraint changes sign parallel to that of the internal vacuum energy at a *different metrical scale*. Gravitationally bound structures will thus represent a scale-free heirarchy of such dynamic equilibrium surfaces which are generally phase transitions at domain boundaries where the net vacuum polarity begins to change. These transitions will be associated not with any constant or function of scale or mass (except derivatively), but with a discontinuity at which local gravitational (-) acceleration goes over into global inflationary (+) acceleration. The suggestion is that this scale-free domain boundary rolls over quite rapidly for all such structures with a critical transition near α_o, the MOND acceleration parameter.

xv.) In summary, this means that instead of treating mass as a scalar constant on the radius of a galaxy or cluster and inferring that a given mass moves 'too fast' to be gravitationally bound, one would treat mass as a radially diminishing component of a conserved angular momentum plotted on a curve of rising inflationary velocity, but, in line with the spirit of MOND there would be only a statistical correlation with distance scale. Cosmologically, if there really is no physically fundamental homogeneity scale then it becomes necessary to try to produce the MOND acceleration parameter from a fractal type of theory, where again one would expect scale-free correlations analogous to the nonlocal long-distance correlations that characterise our network model. It is at least arguable that the intrinsic inflationary function of a superspin network would render natural the resemblance of the galaxy distribution on supercluster scales to a 'foam' of colliding compression wavefronts, as well as supplying an overall accelerating expansion-rate proportional to cosmic scale and thereby obviating (in principle) the need for a superadded 'dark energy'. Intuitively, the mean global geometrical resultant would naturally be 'flat' with $G = 0$, just as the total network 'virtual' self-energy cancels away as a null correction to the 'real'. A zero 'cosmological constant' would therefore occur as an average condition of an effective local field theory of GR spacetime which is 'simultaneously' expanding and contracting, and which is underlain by a nonlocal, inhomogenous, anisotropic, quantum theory based on a scale-free fractal network principle.

xvi.) As mentioned in *7.xii.* above, the renormalisation of constants in a network theory would not imply truly smooth secular variations in these values; nevertheless it would imply global spatial effects that look like past secular temporal variations reducing to vanishing at the here-and-now. In 1999 evidence was produced by Webb *et al.* [103] of apparent variations in the strength of the fine structure constant inferred from displaced absorption lines in QSO spectra at high redshifts, and they further strengthened their case in more recent studies [104, 105]. This is widely interpreted as tentative evidence of a secular variation in one of the components of alpha over look-back times approaching 10 billion years. In essence, if alpha 'has increased' then this appears to mean that c 'has reduced' or e 'has increased'. This chimes with the VSL (varying speed of light) theory proposed in 1999 by Albrecht and Magueijo [106] to address problems with inflation, and more recently Barrow, Maguiejo and Sandvik [107] have proposed a model of variations in e and/or c confined to one early cosmic epoch which fits the data on alpha. Davies *et al.* [108] argue that an increase in e would violate the proposed law of black hole horizon area conservation, and therefore the 2nd law of thermodynamics, implying that the whole variation must be due to a larger value of c in the 'past'. They admit that the chain of inference from the horizon-area constraint remains conjectural (it depends in fact on a great deal of quantum black-hole entropy theory which would invite reinterpretation in a network model; moreover, the overarching laws of thermodynamics become extremely delicate to interpret in a cosmological context). Some variant of VSL appears currently to be favoured. However, note that if one adheres to energy conservation then allowing c^2 to vary upward globally means that m must be allowed to vary downward globally. In observational terms this would mean that an increase in alpha over cosmic time reflects a decrease in mass proportional to scale. This is the relation expected according to our theory.

xvii.) The Webb results are not about the physics of quasars as such but about the physics of large scales. The spectra effectively index pairs of interactions, photon emissions from quasars and absorptions by interstellar gas clouds in an intervening galaxy. A variation in the norm of alpha therefore doesn't mean that 'electron mass was smaller in the past'; it means that the norm of electron mass-energy appropriate to a pair of measurements both made close to the here-and-now is larger than the norm appropriate to a pair of measurements (between quasar target and gas-cloud foresight) effectively made over a cosmic scale of millions or billions of light years. The best constraint on local variations in alpha, derived from the Oklo fossil natural reactor, is tight, on the order of 10^{-17} per year over 2 billion years [109]. Langacker *et al*. [110] point out that this limit is two orders of magnitude smaller than the variation already implied by the QSO data, although Calmet and Fritzsch [111] caution that the Oklo limit is really a limit on a product αM_{π} under the assumption that other strong-interaction parameters remain constant. So the absence of local secular temporal variation is weak positive evidence for the scale-dependent variability predicted by our theory, but arguably this 'recent' data is not probative since the cosmological evidence is strong only at larger red shifts and could also be consistent with highly nonlinear changes in alpha confined to an early epoch of the conventional cosmos. Two tests of the present theory, therefore, would be:

1) that no future evidence for variation in α at any earlier time is found in the physics of the solar neighbourhood; and

2) that analysis of the observations should show a correlation between α and the distance from QSO source to absorber, which will be more direct than the correlation between α and the gross look-back time to the QSO source.

xviii.) It is in fact unlikely that experimental evidence will be found in our immediate neighbourhood to test the nonlinear temporal variation hypothesis. Discovery of a sufficiently ancient 'Oklo' analogue is ruled out since the age of the earth is comparable only to redshift 0.3 or so, and therefore doesn't sample the redshift >1.0 epoch of real interest. However the integrity of the standard model together with the astrophysical theories based on it does represent a sensitive model of primordial solar system physics. For example the electroweak interaction rate that plays an important part in the solar model would be upset by changes in alpha. As Calmet and Fritzsch [112] point out, light-element nucleosynthesis would be sensitive to implied variations in the proton-neutron mass ratio, among other parameters. Banks, Douglas and Dine [113] argue (along with, independently, Kaloper and Susskind [114]) that not only the standard model but also string and M-theory models are equally challenged. Observing that the vacuum energy in any low-energy effective field theory, even independently of any assumptions about the cosmological constant, must depend upon α, leading to 'fantastically tight bounds', they argue that 'such a large variation of a can only be compatible with basic principles of quantum field theory if there is an extraordinary degree of fine tuning of many parameters of the underlying theory.' They say: 'Our overall conclusion is that we do not have *any* field theoretically natural explanations for a variation of the fine structure constant as large as would be required to explain the observations . . . . If these observations are confirmed, one will have to invent some very exotic physics to explain them.'

xix.) A scale-free network model which is not a low-energy effective field theory of the usual kind would in principle avoid the associated field-theoretical vacuum energy problems for the reasons discussed earlier. Also, an effective cosmic temporal variation in fundamental constants becomes a variation in imaginary time only. Since the true (approximate) correlative is emergent real scale rather than any local history there will be no temporal variation on terrestrial laboratory scales and probably no effect on the astrophysics of the local solar neighbourhood (or, of course, of any equivalent stellar neighbourhood). In network terms, a scale-variable mass becomes a natural consequence in principle of an underlying theory rather than an arbitrary correction to a field theory already strained by requiring cancellations of several unnaturally related parameters. The need to preserve the quantum superspin symmetry relation of h and c is seen to be the 'reason' for the renormalisation of mass-energy, and one could say that the 'reason' for an effective field-theoretical spacetime curvature is to allow just this global variation in effective inertial mass. Thus network renormalisation becomes the 'reason' for gravitation; or, inversely, 'gravitation' becomes the agency naturally cancelling the infinities which arise, spuriously, in an effective field-theoretical quantum theory. (Note that GR 'curvature' is directly representable, both in the conventional differential formalism and in the Cayley-Klein algebraic formalism, as a variation in norm of the geometrical constant π, so that the connection back to superspin symmetry - which can be represented as the segment-by-segment renormalisation of π - becomes transparent.)

xx.) It is suggested that the most fruitful general characterisation of the approach advocated here is by way of analogy with the classical black body problem and its solution by the Planck action constant. (See also Section *1.viii.*) A finite cosmic network should behave statistically like a cavity filled with *linear* 'gravitational radiation' in equilibrium, where the quantisation condition on the network means that the 'energy density' is not free to approach infinity in any given volume because 'volume' is quantised. The dimension of quantisation of spacetime volume *is not itself a unit volume*, however (this would lead to paradox in the lower limit of scale), but angular direction, leading to a scale-free *unit distance* as the elementary quantum. This is possible because the 4-space volume of the 'cavity' exists only as a projective relation, an effective field, and the (dis)continuous string of ravelled 1-space constructing the network has in fact a fractal global dimension with no real 'walls' and no real homogeneity scale. In this cavity the linear self-interaction of quanta (network segments) naturally produces a distribution of 'wavelengths'. But these space waves, instead of yielding a spectrum of different peak-to-peak measures of concentric spherical wavefronts expanding through an homogeneous field, will occur *nonlocally* on the network lattice as *statistical* distributions of real distances (actually half-wavelengths) between pairs of position states, not as local spatial distributions of imaginary amplitudes. In other words the informational structure of the emergent 'gravitational field' will be dispersed - holographically, as it were - as waves encoded in an abstract 'information field' rather than as ripples in a field metric.

xxi.) To illuminate the change of perspective implied here we can pose a fantasy question: If, in another reality, Planck and Einstein had been commissioned, early in the last century, to find a quantum field theory of gravitational black body radiation in a finite universe, how might they have approached it? One imagines that they would first take the gravitational energy density in a finite 4-space cavity as a statistical mix of waves of all lengths, amplitudes and directions, finding a successful analogue of the Rayleigh-Jeans limit for long waves and applying an *ad hoc* analogue of the Wien displacement law as a correction for short wavelengths. They would conclude that quantisation - either of the mass-charge coupling to the field or of the radiation field itself - will prevent the gravitational energy density going to infinity at short wavelengths. Einstein would favour quantising the radiation field where Planck would favour quantising the mass-coupling. Einstein would win on the strength of a statistical thermodynamical argument. They would then attempt to recover a continuous wave model of spacetime from a formula for the mean square fluctuation of numbers of gravitons of energy $h\nu$ per unit volume. (This time Einstein would not look for experimental support in some gravitational analogue of Lenard's photoelectric effect, knowing that gravitational radiation must be too weak to dislodge particles from any surface.)

xxii.) Now this may not look a very fair picture of any current quantum gravity programme! But it is in the spirit of the assumptions behind the modern field-theoretic ambition to make GR spacetime dual with a Planck-scale ideal quantum gas. The difference in a scale-free network theory is that gravitational quanta will not mimic the dissolution of 4-space into a particulate gas of unmeasurables; rather the gravitational black body radiation will distribute itself through the 10^{80}-space 'cavity' in the form of a spectrum of measurable cosmic distances. In other words, instead of postulating a nonlinear quantum gas ulterior to the particles of mass-energy that we observe, the network view is that these 'particles', when supersymmetrically paired as linearly-interacting nonlocal network elements, *are already* (statistically speaking) *an ideal quantum-gravity gas*. From our point of view, the black body law which underlies basic quantum theory, and which also permits modelling of the cosmos as a radiation-filled cavity, stems directly from the radical linearity of the network self-interaction. It is the deep and perfect generality of this network principle that allows a cosmological model based on the empirically-discovered thermodynamical behaviour of hot ovens to so successfully represent statistical properties of the actual fractal cavity, at least up to the Grand Unification energy (of the model) of about 10^{28} kelvins, which is well 'behind' the last scattering surface of the CMB (but frozen in to it in the form of its pattern of 10^{-5} temperature fluctuations).

For this reason the black body statistics allow us to say something about the way the spectrum of distances ought to be distributed.

xxiii.) In the inflationary standard model the huge superluminal inflation at the time of GUT symmetry-breaking is held to have imprinted scale-free microscopic quantum flux on 4-space and so to have frozen-in the density fluctuations from which incipient cosmic structure emerged. This regime, mapped onto the last scattering surface as the 10^{-5} temperature fluctuations recorded by COBE, can (with a degree of approximation) be regarded for our purposes as the effective 'wall' of the 4-space radiation cavity and the GUT energy as its equilibrium temperature. But this effective radiation temperature is not the same as a gravitational temperature, of course. In a network theory this is because there is no real gravitational 'field' and no characteristic gravitational energy. Gravitational energy is quantised over *all* local scales, not just in some global limit, because it is precisely the function of emergent scale to preserve the conjugate variability of space-time and space-energy for all possible angular relations among all 10^{80} intrinsically scale-free Planck oscillators in the network. In the standard model, on the other hand, there is a characteristic gravitational limit of both scale and energy, in a regime located at a still 'earlier' epoch, the Planck time, when the universe is 'only 10^{-43} sec old' with a temperature of 10^{32} °K. The GUT regime is therefore not the gravitational 'wall' of the cavity in the standard model. The electroweak and strong nuclear interactions unify satisfactorily at the supersymmetric GUT point, but generally speaking the big problem remains connecting the GUT regime with the Planck regime so as to bring gravity into the fold in a TOE. From the point of view of a network theory this becomes a non-problem.

xxiv.) Our rationale for this can be set out as follows. Global gravitation and inflation represent opposite signs of a coemergent dipole in the supersymmetric network. Spacetime is not a fundamental substrate but a projective representation of this emergent property, having merely real, merely imaginary and *actual* (i.e., complex) components. The merely real components are Lorentz-invariant relations between observables and the 4-space 'cavity' is a merely imaginary projective volume containing them. This imaginary volume does not support wave amplitudes; only the complex linear 'volume elements' constructing the network support (complex) wave amplitudes, and the sum over all such *actual* amplitudes gives the phase of electrodynamics. This phase already 'includes gravity', not just in the form of a short-scale high-energy correction (as represented in the imaginary unification regime lying 'beyond' the GUT wall in the standard model) but in the form of phonon modes of the string occurring at *all* scales arbitrarily, including long-scale, low-energy phonons. This phonon 'field' is a scale-free fractal. As the electrodynamical phase of the folded string self-inflates (in imaginary time) it cools and a scatter of real distances freezes out over all scales. The emergent spin-2 gravitational phonon wavelength obviously increases as double the real scale of the string segment, so that at the largest scale - comparable to the horizon radius - whole phonon wavelengths of the order of 10^{10} light years reach vanishingly small energies. In this sense the gravitational temperature T_G of the GUT wall in fact approaches 0°K, in equilibrium with a gravitational 'radiation' temperature also approaching zero. 'Approaching' zero means the vacuum energy reciprocal to a GUT temperature $T = 10^{28}$ °K. So with T normalised to unity $T_G = 10^{-28}$ °K. This has the significance that the length of the longest measurable spacetime wave at the 'present epoch' is of order 10^{28} cm with the cavity radiation temperature reduced from 10^{28} °K to order unity (2.73°K). In other words the ratio of cavity 'scale' to cavity equilibrium temperature is governed by a constant of proportionality of order unity at any epoch. This constant is evidently related to the Wien displacement constant, which is independent of the energy, the scale of the cavity, its material or its geometry. It is a universal constant of cavity radiation in equilibrium and has the experimental value $C_o = 0.2898$ cm/°K.

xxv.) Our desired scenario, then, is this: The 'gravitational' coupling emerges from a scalar inflationary background in the form of relations of real distances at what is now a 'triple point' representing the supersymmetric convergence of electroweak, strong and gravitational forces. There is no gravitational TOE scale 'beyond' the effective GUT regime of 10^{28} °K, and no meaning to the field-theoretical extrapolation of GR to still hotter and denser states and ultimately to a singularity. There will be no inflationary era either, of course, since the GUT scale is a horizon on emergent spacetime. Inflation becomes a functional property of the general nonlocal interconnectivity of the network rather than an historical plug-in, and the very long-wavelength TOE-equivalent space waves that one gets by putting in the reciprocal of the Planck temperature (10^{-32}°K) for the gravitational vacuum temperature become imaginary phonon modes, giving a λ_{max} some 10^3 times the radius of the observable universe. (It seems doubtful that such imaginary phonon modes can be said to have any physical meaning. They can be considered to 'wrap around' the GUT-scale horizon. This wrapping would be analogous to the winding modes of superstrings wrapping compactified dimensions at the Planck distance, where that theory discovers its own version of the renormalisation of emergent [global] scale. In a similar way, a phonon wavelength longer than any measurable real network string segment cannot be used as a clock; it has no frequency, so that real scale - and energy - become completely indeterminate.)

xxvi.) Now our analogue of the spectrum of quantised gravitational radiation density in the cavity will be neither that of a gas of n free particles nor that of a mixture of continuous harmonic waves, but rather a histogram showing a frequency distribution of *n* discrete, measurable distances. Obviously 'measurable' means observable, which in terms of the usual effective field model means observable at our cosmic epoch, and this distribution of 'spacetime quanta' must preserve the characteristic *gravitational* black body signature of the cavity just as a flux of photons (the CMB) preserves its electromagnetic black body signature. Based on a number of arguments, then, two further predictions of this model will be:

> *1) That the global, effective, geometry at the largest scale should be perfectly simple (even though the topology of 1-space is multiply connected, exhaustively at 10^{40} nodes, reiterating itself on all scales). The topology of 4-space will not be multiply connected because it is only a projective 'cavity' whose 'winding modes' are imaginary; and*
>
> *2) That the frequency distribution of cosmic distances in a mass-scale regime associated with the cosmic limit of gravitational binding (the global phase transition; see note 27) will resemble a black body spectrum with a peak calculable from the equivalent cavity wall temperature.*

Both of these predictions are testable against existing and future galaxy surveys.

xxvii.) Galaxy clusters are the largest gravitationally bound structures, so the intercluster distance scale defines the limit of gravitational binding, or in network terms the phase transition from gravitational to inflational dominance. This is the supercluster/complex regime. (The characteristic mass scale of superclusters - in terms of the standard cosmological models - is around 10^{16} to10^{17} solar masses, or about 10^{-5} of the observable universe mass scale of 10^{22} solar masses.) The statistical distribution of intercluster distances should therefore measure the distribution of *half*-wavelengths associated with the black body temperature *T*, and will have a mode given by

$$\tfrac{1}{2}\lambda_{max}T = \tfrac{1}{2}C_o \text{ cm/°K} \qquad (7.1)$$

where C_o is the Wien displacement constant for cavity radiation. For $T = 10^{-28}$ K this leads us to expect: 1) In general, a curve which does not exhibit multiple peaks indicative of repetitive global topology; and 2) specifically, a black body spectrum of separation distances (half-wavelengths) with a peak at 1.45 x 10^{27}cm, or a little over 1 billion light years.

xxviii.) This can be compared with the result of a study by Luminet, Starkman and Weeks [116] analysing the frequency distribution of pair separations between all galaxy clusters within a sphere about 4 billion light years in diameter in search of a pattern of peaks indicative of involuted spacetime topology. Their result, shown in Fig. 7.1, gives no indication of multiply-connected topology, and instead closely resembles a black body curve with a peak at a little over 1 billion light

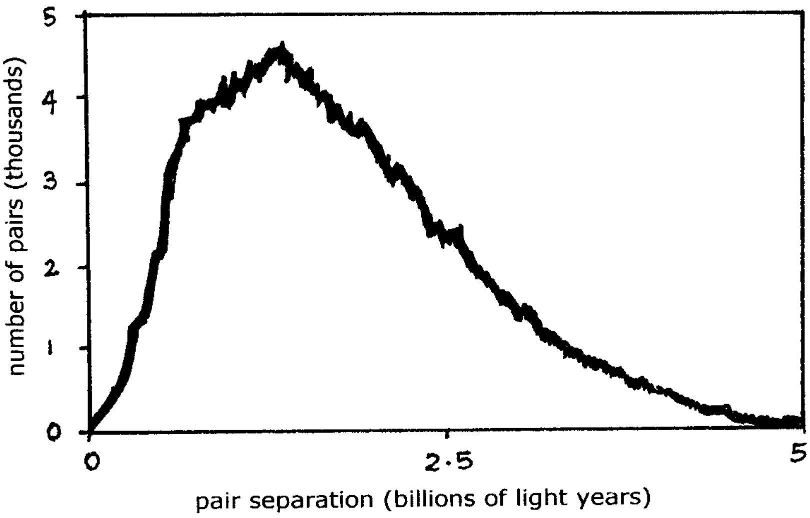

Fig.7.1. Distances between galaxy clusters within roughly two light years of earth. After Luminet, Starkman & Weeks, 2002.

years (about 1.25 x 10^{27} cm). Given the approximations involved this match can be considered good. Luminet, Starkman and Weeks suggest that evidence of exotic structure may yet appear in studies of cluster separations in larger data samples extending to larger look-back times, because there is nothing to rule out multiply-connected global topology in GR. However such evidence in future high-redshift galaxy surveys would probably argue against a scale-free network model of this kind.

xxix.) Finally I refer to this important remark by Sylos Labini and Pietronero [117]: 'A crucial point to understand is therefore the origin of the scale-invariance in the gravitational clustering phenomenon. This would correspond to the understanding of the origin of self-gravitating fractal structures and of the properties of Self-Organized Criticality (SOC) from the knowledge of the microscopic physical processes at the basis of this phenomenon.' They advocate a new approach from the directions of statistical physics and complexity theory. But the contention of this essay is that they may be mistaken in seeking a basis for cosmic SOC in '*microscopic* physical processes', in the sense that no physical processes in a radically scale-free fractal universe can properly be understood as microscopic. It is argued that only a radically scale-free fractal dynamic operating on processes at all scales will get rid of the problems inherent in scale-dependent effective field theory in a fully self-consistent way.

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