Simple introduction to "Cloud QED" physics

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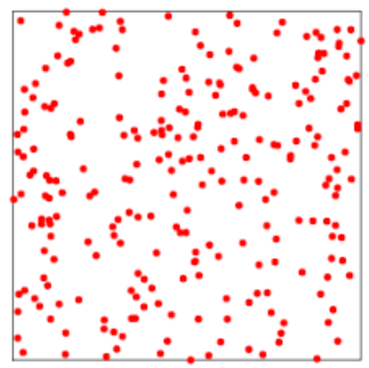
Abstract. This is a short simple exposition of my book-in-progress Completing Quantum Electrodynamics and other Quantum Field Theories with "cloud" (and perhaps even creating "quantum gravity" & "theory of everything"). If said book ever manages to get published in print, then the present essay might be a good "foreword" for it.

When one draft of my book was around 200 pages long, I showed it to famous physicist Gerard t'Hooft. He soon remarked

> I am afraid you will have to add minus 199 pages to make the argument credible.

This essay is my response to that complaint! I'll try to describe the main cloud QED ideas, in a brief way everyone can comprehend.

Ultimately, physics is very simple.



Cloud postulates that spacetime is filled with special random points, called **raindrops**, as pictured at right. Unlike the 2-dimensional picture, spacetime is 3+1 dimensional, with one time coordinate t and three spatial coordinates x,y,z. It is best to measure those coordinates not in seconds and meters, but rather in natural Planck units: we measure t in "Planck time" units t_{Pl}=5.391247(60)×10^{-44} second, and x,y,z in "Planck length" units $L_{Pl}=ct_{Pl}$≈1.616255(18)×10^{-35} meter. [The numbers in parentheses denote uncertainties in the final decimals, e.g. "1.2345(78)" means "1.2345 with RMS uncertainty ±0.0078"; and c=299792458 meter/sec denotes the speed of light.] A hyperrectangle with sides A,B,C Planck lengths and duration D Planck times has 4-volume V=ABCD Planck 4-volume units. One advantage of Planck units is that with them, c=1, i.e. light travels 1 length unit during each time unit. That makes life easier because we no longer need to keep writing factors of c inside formulas ($E=mc^2$ becomes E=m), and no longer need to remember the magic number 299792458. The natural Planck yardsticks are very tiny in human terms, e.g. ≈10^{17} times tinier than a proton.

To make an analogy: radioactive carbon-14 atoms in the atmosphere continually randomly explode. If you'd never heard of radioactivity and discovered tiny flashes of light coming at random times from random locations everywhere in the air, you'd think "I've discovered a new law of physics!" or at least "a new property of air!" Well, the locations and instants of those explosions are much like raindrops. Except it isn't "the atmosphere," it is all "space." Space itself is a "radioactive" substance, but with no explosions – raindrops are silent and neither release nor absorb any energy. This pseudo-radioactivity of space is a new law of physics. And the 4-dimensional number-density ρ_{rain} of raindrops is new fundamental physical constant (analogous to the number density of $^{14}CO_2$ molecules in air divided by the mean lifetime of ^{14}C) whose exact value is not yet known.

In principle all fundamental constants in cloud QED may be determined after enough computational and experimental work, but what I've done falls considerably short of "enough." Nevertheless, I have good reason to believe that if time and space are measured in Planck units, then $10^{-6}<\rho_{rain}<10^9$. So in human units ρ_{rain} is enormous: $4\times10^{141 \text{ to } 156}$ raindrops per cubic meter of space during 1 second of time. Any 4-dimensional region of spacetime of 4-volume V contains, on average, $V\rho_{rain}$ raindrops. It could contain more or fewer – the number is governed by the Poisson distribution – but that is the average. Note that raindrops, since Poisson-random, are generic with probability=1, e.g. no finite raindrop-subset exists whose coordinates satisfy any nontautological polynomial equation with integer coefficients. Importantly, even though differently-moving observers *disagree* about lengths and times thanks to Einstein's "special relativity," *all observers agree* with the statement "spacetime is filled with Poisson-random raindrops at 4-dimensional number density ρ_{rain}" and all observers agree on the constant numerical value of ρ_{rain}.

Now if the "background" spacetime were Minkowski, then the **pseudodistance** between two raindrops located at (T;X,Y,Z) and (t;x,y,z) would obey

$$\text{PsuDist}^2 = (X-x)^2 + (Y-y)^2 + (Z-z)^2 - (T-t)^2.$$

Unlike "distances" (which never are negative), note that squared *pseudo*distances can be either positive or negative, corresponding to (unsquared) pseudodistances that are *real*-valued ("spacelike") or *imaginary*-valued ("timelike") respectively.

Distinct points can have pseudodistance=0, in which case their separation is called "lightlike."

Now actually, cloud postulates that the pseudodistance formula is *not* Minkowski's "flat spacetime" formula above, but rather de Sitter's "constant curvature spacetime."

Let me explain what de Sitter is by starting with something more familiar: a flat tabletop – i.e. Euclidean geometry of the XY plane. One nonEuclidean, i.e. constant-curvature, analogue of that would be the 2D surface of a sphere in Euclidean 3-dimensional (X,Y,Z) space, which as an equation is the surface

$$X^2 + Y^2 + Z^2 = H^2$$

for a sphere of constant radius=H, and we agree to use as the surface metric on that sphere the one induced by the usual 3D Euclidean metric. But there is one other nonEuclidean plane geometry, discovered by Janos Bolyai (1802-1860) and N.I.Lobachevsky (1792-1856) independently. It is called "hyperbolic geometry." It arises on the 2D surface

$$T^2 = H^2 + X^2 + Y^2$$

in *Minkowskian* (1+2)-dimensional (T;X,Y) spacetime, again with H>0 denoting a constant, and where we agree to use as the surface metric the one induced by the usual 3D Minkowski pseudometric. OK, now let us boldly go to 3+1 dimensions. De Sitter spacetime arises as the (3+1)-dimensional surface

$$W^2 + X^2 + Y^2 + Z^2 = H^2 + T^2$$

inside (1+4)-dimensional (T;W,X,Y,Z) Minkowskian spacetime, where we agree to use as the surface pseudometric, the one induced by the Minkowski pseudometric in the (1+4)-spacetime. Here the constant H>0 is called the "Hubble length" (or "Hubble time," if regarded as a time; we are using units with c=1 so space and time are measured in identical units).

Furthermore, imagine that each raindrop is not a single "point," but rather a certain D-dimensional ($D\in\{1,2,3\}$) compact boundaryless manifold. I call these "bricks." This name carries the advantage that the resulting physics is "rain of bricks," which sounds cool. A priori I prefer (and this choice also seems the one likeliest to work once we add gravitons) the *simplest* kind of brick, namely the 1-dimensional kind, namely the perimeter of a circle with radius=L_{brick}. This choice is uniquely forced because, topologically speaking, there is only one 1-dimensional compact boundaryless manifold. However, we also could imagine 2- or 3-dimensional bricks, which conceivably might have advantages. In those cases there would be more possible topology- and geometry-choices to worry about. The *simplest* choice (in the sense that it uniquely maximizes *symmetry* and is describable with only a *single* size parameter) then would be to assume each D-brick is a D-sphere, namely the boundary of a Euclidean (D+1)-dimensional ball of radius=L_{brick}. Cloud physics is only done in a **limit** in which $L_{brick}\to 0+$ so that bricks shrink down to single-point raindrops. However, before we take that limit, bricks have nonzero finite sizes. The fundamental distance formula then is

$$\mathrm{PsuDist}^2 = \mathrm{DeSitterPsuDist}(X,X')^2 + \mathrm{WithinBrickDistance}(A,A')^2$$

which in the simplest (1-dimensional bricks) scenario, is

$$\mathrm{PsuDist}^2 = \mathrm{DeSitterPsuDist}(X,X')^2 + (\theta-\theta' \bmod 2\pi)^2(L_{brick})^2$$

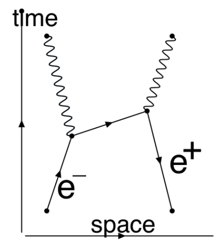
where the two points lie in raindrops located at the 4-vectors X and X' in the background de Sitter spacetime, and within their bricks the points are at angles θ and θ' along the circles that are those bricks. Notice that the within-brick degrees of freedom (here θ) are *orthogonal* to the 4 degrees of freedom inside X. Consequently, although bricks are non-point extended objects, they are single points in the de Sitter coordinates considered alone. Their extension occurs within extra dimensions that do not lie within de Sitter spacetime.

"QED" stands for "quantum electrodynamics," a simplified model of physics in which there are only 3 kinds of particles: electrons, positrons (anti-electrons), and photons. Fancier quantum field theories (QFTs), e.g. the "standard model" (SM), involve additional particle types such as quarks and neutrinos (and their anti-particles), and W-bosons, Z-bosons, Higgs and gluons. Those make the mathematics more complicated because the QFTs now are "nonAbelian" gauge theories. If anybody were ever to add gravity to the standard model (which throughout the past has seemed impossible), then there would be an additional spin-2 massless boson called the "graviton." That would add a new level of mathematical complexity because the QFTs would now be "non-renormalizable," posing problems that somehow would need to be overcome.

I'll mainly focus on cloud-ified QED here, but one also can cloud-ify fancier QFTs like the SM in essentially the same manner. Adding gravity might also be possible with more care.

There are only two phenomena that ever happen in cloud QED physics:

1. **Propagation**: a particle (for QED, either a photon, electron, or positron) travels from one raindrop to another. (Actually, to a quantum superposition of others.)
2. **Interaction** only occurs on raindrops, and not in the rest of de Sitter spacetime. In QED, the only allowed interactions are: an electron (or positron) *emits* or *absorbs* a photon.

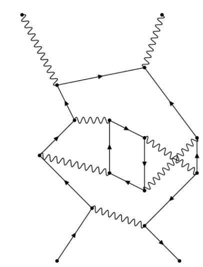


Time tricks. It is mathematically possible to regard positrons as electrons that propagate "backward in time" which makes life more convenient because then electrons and positrons (more generally, fermions and their antifermions) are the "same" particle so you can re-use the electron formulas with timespan-signs changed. Similarly, photon "emission" and "absorption" can be regarded as the same, only time- and charge-reversed.

Example. Let's say an electron and a positron, both propagating forward in time as usual, happen to annihilate, yielding two gamma-ray photons. That story is described by the "**Feynman diagram**" shown above right.

In the "positrons are electrons moving backwards in time" re-interpretation of that story, an electron (e^-, propagating on straight line) emits a photon (propagation depicted by lefthand wiggly line), then emits a second photon (righthand wiggly line); and during the second emission converts to a positron (e^+) which now continues propagating, but now backwards in time (fermion propagation directions shown by arrows). The 2 vertices of the diagram, where the emission and absorption occur, both must be located on raindrops. In any given finite 4-volume spacetime region, such as 1×1×1 meter × 1 second 4-box, there are only a finite set of raindrops. (Box is depicted as 2-dimensional in the picture, with finite area.) It is a very large set, but finite. Therefore this diagram topology can occur in only a finite number of geometrical ways within such a box. In *un*bounded (1+3)-dimensional spacetime it could occur in infinitely many ways – albeit only a countable, not uncountable, infinity, since the number of raindrops is countable.

If we were to rotate that picture anticlockwise by about 90°, or equivalently just interchange that figure's notions of the "time" and "space" directions, then it would describe a different story: "an electron and photon scatter off each other." *Micro*scopically, the electron absorbs the photon, getting deflected; then emits a different photon (causing a second deflection) then both continue on. The new photon in general has different wavelength and direction than the old photon. The electron's momentum also changes. *Macro*scopically, "a photon and electron scatter off each other, and I do not know what happened microscopically."



The importance of the distinction between the micro- and macroscopic versions of these stories is that the same macro-phenomenon can occur in many microscopically inequivalent ways. For example, the original "positron & electron annihilate" story also could occur via the much more complicated, and different, microscopic history shown in the next (12-vertex) Feynman diagram. Macroscopically, it describes the same phenomenon as the original 2-vertex diagram. But the internal microscopic details are quite different.

Cloud-QED Feynman diagram vertices are required to be

- [Topological rule] 3-valent, featuring one outgoing →, one incoming →, and one photon ~~~ line. There also can be "input" and "output" lines to a Feynman diagram, e.g. in the topmost diagram, the electron & positron lines were inputs and the two photon lines outputs. These traditionally have been regarded as lines with endpoints at only one end, extending infinitely with no other end. However, cloud instead usually shall regard inputs and outputs as *having* "other ends" that are *blurred* over a known "pseudoball" region of spacetime (i.e. a set which is compact in a Euclideanized version of spacetime), hence originated from a finite raindrop set.
- [Geometric rule] located on a raindrop, with at most one vertex per raindrop.

Any diagram, with any finite number of vertices, obeying those topological and geometrical rules is allowed. And each corresponds to a story. (For SM Feynman diagrams, there are more allowed kinds of particles, i.e. more types of line, and a larger finite set of allowed vertex types, than in QED.)

Each cloud-QED Feynman diagram has a "**probability amplitude**" Ψ which is *not* the same thing as a "probability." "Probabilities" are nonnegative *real* numbers. But QED probability *amplitudes* are *complex-vector*-valued. The value of Ψ for each Feynman diagram is given by a formula which is a known (once the topology/combinatorics of that diagram is specified) function of (a) the coordinates of its vertices (which depends on them only via the pseudolengths of the diagram edges), and (b) information about the input and output lines of that diagram.

This formula is essentially the same as the old-style QED "unrenormalized" before-Feynman-integration formula in "position space" – but with a few differences:

1. Old-style QED usually was done in "momentum space" (which makes the formulas simpler) but in cloud-QED we stay in position space.
2. Cloud QED uses *un*renormalized formulas only, and based on "bare" rather than "dressed" particle masses.
3. Old style QED was always done in Minkowski spacetime. But cloud QED needs to be done in de Sitter spacetime using propagator formulas designed for de Sitter. (The de Sitter formulas include the Minkowski formulas as a limit case.)

4. If we are using some positive brick-size $L_{brick}>0$, because we have not yet taken the limit $L_{brick}\to 0+$, then we need to average over all within-brick positional degrees of freedom.
5. We want *summations* over raindrops to be regardable as "Monte Carlo approximations" to *integrals* over all spacetime. To make that happen we need to include certain normalization factors – basically, appropriate powers of ρ_{rain}.

All physics ever does, is simply to sum the diagram amplitudes. That is, suppose you specify, or partially specify, the inputs of a physical process, and you want to know what the outputs will be. ("Specify" would mean giving the wavefunction Ψ of the inputs. "Partially specify" would mean giving a probability distribution over such wavefunctions, or equivalently a Von Neumann density matrix.) You write down every possible Feynman diagram compatible with those inputs, then sum their probability amplitudes. The final result is a function of output state, telling you its probability amplitude, i.e. telling you the wavefunction Ψ of the outputs. The sum, over output states $s\in S$, of the complex vector-norm $\sum_{s\in S}\Psi^*(s)\cdot\Psi(s)$ then tells you the probability that the output state s will lie in the state-set S. [You, if simulating physics, could then output just one s, with probability $\Psi^*(s)\cdot\Psi(s)$.] For example, suppose your physical system was a "cat" and some subset S of possible output-states correspond to your notion of a "live cat," while the rest do not. Then the sum over $s\in S$ of the probability for s is the chance you'll still have a live cat at the end of that physical experiment. Now actually, really, physics ends up with a "superposition" of states s, some representing a live cat, some not, and never actually samples just one state s. If the physical system consists of both the cat, and measurement apparatus for detecting, e.g, "cat liveness," then it will end up in a superposition of different measurement outcomes.

That sounds weird. However, really, it isn't. What are "weird" are quantum superpositions whose complex amplitudes get "entangled" in complicated ways and do not behave like ordinary probabilities. What is "non-weird" is complex amplitudes that *do* behave like classical probabilities. In Von Neumann's density matrix formulation, the latter correspond to *diagonal* density matrices. The off-diagonal entries of those matrices are what make quantum mechanical probability amplitudes behave in ways ordinary probabilities cannot. Now if something causes the off-diagonal elements of the density matrix all to have small magnitudes, and/or something causes them all to get multiplied by *independent random* unit-norm complex numbers ("decoherence," aka "**dephasing**"), then, with overwhelmingly high probability, life seems non-weird. Well, raindrop locations *are* independent random variables. They cause such dephasing. If we consider you (weirdly) being in a superposition of being in Paris and Tokyo, the (Paris,Paris) and (Tokyo,Tokyo) diagonal entries of the density matrix correspond to the ordinary probabilities you are in Paris, or that you are in Tokyo. The off-diagonal (Paris,Tokyo) and (Tokyo,Paris) entries of the density matrix, are weird. However, because the raindrops near Paris are random in a way entirely independent of the raindrops near Tokyo, and there are enormous numbers of them that affect every interaction and self-energy of every fundamental particle inside you, those two matrix entries will rapidly get multiplied by random unrelated complex phase angles. This will "dephase" them.

In previous discussions (sans Clouds) of dephasing, this sort of dephasing was explained because, e.g, you continually interact with, e.g, air molecules, sunlight, neutrinos, etc in Tokyo, differently than you interact with the different air molecules, sunlight, neutrinos, etc in Paris. Of course, there are far fewer air molecules, sun-photons, etc, encountered far less frequently, than raindrops. Nevertheless, there are an enormous number of them – enough to dephase you far quicker than human experiential timescales. Which explains why you've never experienced the feeling of being in superposition of being in Paris or Tokyo. You've only experienced one, or the other, of those two possible threads of your life history; not both. And once two such threads bifurcate, they never recombine because that complex phase-angle randomization is effectively an uninvertible 1-to-many map. It is something like mixing a drop of red dye into the ocean. Once you do, it is extremely unlikely those dye molecules will un-mix. Similarly, once randomized, it is extremely unlikely those complex phase angles of your off-diagonal density matrix entries can ever get restored. (In the ocean case, there are only a finite set of water and dye molecules involved, so there is a tiny but nonzero unmixing probability; but in contrast, an infinitude of truly-random raindrops keep coming everywhere forever.) Due to the law that each raindrop can be involved in at most one event (Feynman diagram vertex), it is *inherently* impossible for any second event to ever revisit that raindrop to try to learn what it needs to learn to undo the randomness in the first event. Thus raindrop-caused randomness is inherently irreversible, unlike air-molecule-caused randomization. This causes the mathematical entropy (of the probability distribution over wavefunctions) to *increase* but never decrease, which is a time-irreversibility property for cloud QED. This contrasts with old-style QFTs, which all obeyed "CPT symmetry," a time-reversibility property, and in which entropy increase was inherently impossible except via the introduction of extraneous magic "measurement" operations. This had been a huge foundational problem underlying all prior quantum mechanics, but cloud solves it.

To make that clearer, consider the following thought-experiment. Suppose we carefully shielded out the sunlight, vacuumed out the air, magically somehow shielded out even neutrinos, etc. from Paris and Tokyo. Or suppose the air molecules *themselves* had somehow been placed in a nasty Paris-Tokyo macro-superposition/entanglement state before the experiment began. Could we *then* create such a "macroscopic superposition"? With old physics, the answer would have been "maybe." With cloud, the answer is NO. Because raindrops are just there doing what they do, regardless of shielding, vacuum pumping, or anything else. And the decoherence caused by this effect always is *position-based*, causing the primacy of the positional basis over all others. In previous quantum mechanics, all bases of "Hilbert space" were equivalent so there could be no special favortism for the position basis. With cloud, there is.

As a result, "weird" positional superpositions, such as you being in both Tokyo and Paris at the same time, or cats being alive and dead at the same time, or any two-location superposition of almost any macroscopic object, become overwhelmingly improbable. With overwhelming probability you are in just one place. *Which* place you will go to – Tokyo or Paris – could still be an unpredictable random event; but one governed, to very good approximation, by the ordinary laws of probability.

Notice that cloud QED physics is completely *deterministic* once all the raindrop locations are known. However, given that they are (i) random and (ii) not known to us, physics is *randomized*, and the summation algorithmic-process I discussed will only return one *sample* from the output probability distribution. (Or: will return a probability distribution over wave functions, also interpretable as a Von Neumann density matrix – anyhow that is what cloud physics itself does. Note cloud with unspecified raindrop locations thus converts "pure states" into "probability mixtures," which is *not* merely performing a unitary transformation.) To simulate physics, just rerun your simulation-computer with new random raindrop location-guesses to get a new output sample, and do so as many times as you want. You can then compare the resulting predictions versus experiment, and similarly re-run the experiment as many times as you want. Then theory versus experiment becomes an "apples vs. apples" comparison. The theory is refuted if the two probability distributions statistically-significantly differ.

Raindrop location-randomness is the sole source of nondeterminism in cloud physics. And given that propagators obey known linear PDEs, the interactions on raindrops are the sole source of nonlinearity in physics.

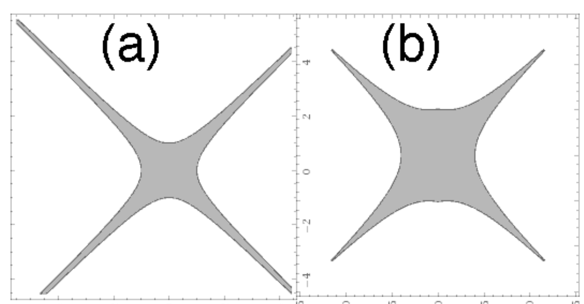
Performing the diagram summation is – warning! – no trivial matter. First of all, the number of raindrops usually is enormous (indeed, we'd argued it is countably infinite), and the number of, say, 100-vertex diagrams seems way more enormous, e.g. of order more than the 100th power of the raindrop count! And then the 10000-vertex diagrams are way more numerous than that! But even if you had a miraculous super-duper-computer capable of performing even ridiculously huge computations, then the summation task still would not be trivial, because I have not yet described the crucial "**fancy limiting process**" that defines how to perform it. We now do so.

When we sum the diagram amplitudes, there are three parameters to keep in mind: R, N, and L_{brick}. Here **R**>0 is a real-valued length-scale parameter (measured in Planck length units):

> **R-demands:** We only allow diagrams which, geometrically, have maximum intervertex |pseudodistance|≤R, minimum intervertex |pseudodistance|≥R^{-c}, and more generally, such that every (k+1)-vertex subset has convex hull with k-dimensional pseudoarea A obeying R^{-kc}≤|A|≤R^k for each k∈{1,2,3,4}.

The integer **N**≥0 is the maximum number of vertices (interactions) we permit in any diagram. And we already discussed $\mathbf{L_{brick}}$>0, the "brick size" length-parameter. To perform full summation, we need to define a limiting process in which, simultaneously and in the right joint manner, R→+∞, N→+∞, and L_{brick}→0+. This process will be defined by power laws: N≈R^a and L_{brick}≈R^{-b} for appropriate positive constants a, b and c – whereupon we simply take the ordinary 1-dimensional limit R→+∞. Apparently, many choices of (a,b,c) satisfy the **exponent conditions** saying it works. Any choice near-enough to (1.93, 0.22, 6.04) should work.

Crucial to understanding which exponent-triples work and why, are numerous "**mensuration lemmas**." Here are some of the more important:



$|t^2-x^2|<1$. Arms extend infinitely; area=logarithmically infinite.

$\max(|t^2-(x-1)^2|, |t^2-(x+1)^2|)<5^2$. Compact support; L_5 fits inside 27x27 square.

1. Among N random-uniform points in a (1+3)-dimensional hypercube with 4-volume N, the *J*th-smallest pair |PsuDist| will be of order $J^{1/2}N^{-3/4}$ with probability→1 when N→∞; the *J*th-smallest triangle |PsuArea| defined by 3 points will be of order $J^{1/2}N^{-1}$; the *J*th-smallest tetrahedron |PsuVolume| defined by 4 points will be of order $J^{1/2}N^{-5/4\pm o(1)}$; and the *J*th-smallest simplex |PsuVolume| defined by 5 points will be of order $J \cdot N^{-4}$. (If we instead enquire about these quantities when one of the points in the pair, triple, 4-tuple, or 5-tuple of points is *not* a raindrop, but rather demanded to be the hypercube centerpoint, then we get the same answers except "J" in the formulas must be replaced by "JN.")
2. All of (1+3)-spacetime has infinite 4-volume and hence contains an infinite number of raindrops.
3. For any fixed R>0, the set of points X with |PsuDist(X,A)|≤R, where A is any particular fixed point (I call this region A's "**R-thickened light cone**"), also has infinite 4-volume. A (1+1)-dimensional version of this set is pictured in image (a) at right; in that dimension it has merely-logarithmically-infinite area.
4. Also for any fixed 0≤Q<R, the set of points X with Q≤|PsuDist(X,A)|≤R, where A is any particular fixed point, also has infinite 4-volume.
5. For any fixed R>0, the set of points X with |PsuDist(X,A)|≤R *and* |PsuDist(X,B)|≤R where A and B denote two particular fixed points (this region is the set-intersection of A's and B's two R-thickened light cones), also has infinite 4-volume. A (1+1)-dimensional version of this set is pictured in image (b) at right; in that dimension it generically has *finite* area and indeed the

particular thickened-light-cone intersection pictured, using A=(0;-1), B=(0;+1), and R=5, is contained within a 27×27 square box.

6. For any fixed R>0, the set of points X with |PsuDist(X,A)|≤R and |PsuDist(X,B)|≤R and |PsuDist(X,C)|≤R where A,B, and C denote three generic particular fixed points (this region is the set-intersection of A, B, and C's three R-thickened light cones), also has infinite 4-volume, albeit now only "logarithmically infinite."
7. **BUT**, for any fixed R>0, the set of points X with |PsuDist(X,A)|≤R and |PsuDist(X,B)|≤R and |PsuDist(X,C)|≤R and |PsuDist(X,D)|≤R where A,B,C and D denote four generic particular fixed points (this region is the set-intersection of A, B, C and D's **four** R-thickened light cones), is a pseudoball with only **finite** 4-volume. I call this generic-finiteness claim the "**tetrahedron lemma**." And more generally, if we were in (1+d)-dimensional spacetime, d≥1, then the intersection of K generic-centered R-thickened light cones, has infinite d-volume if K≤d, albeit only logarithmically-infinite if K=d; but is a pseudoball with *finite* d-volume if K≥d+1.
8. But for *non*generic A,B,C,D, such as all lightlike-separated along a single line, the volume still could be infinite. I.e. that volume, although generically finite, can be unboundedly large. To avoid that defect, we can add the additional R-demands, e.g. that R^{-c}≤|PsuDist(P,Q)|≤R for every pair (P,Q) of distinct members of {A,B,C,D,X}. That suffices to yield a set of X, defined in an observer-independent manner, having 4-volume **bounded** by a known function of R.

Because of the tetrahedron lemma and cloud's "at most one vertex per raindrop" rule, the set of N-vertex diagrams with N≥5 (for all infinity such N *combined*) will, at any given length scale R>0, be *finite*, with probability=1. And

Diagram Fact: every SM Feynman diagram always has a number V of internal vertices and #inputs=A and #outputs=B obeying A+V+B≥4 if V≥1. **More strongly:** All SM Feynman diagrams with V≥1 obey A+V≥4 and **A+V+B≥6** except for a finite set of diagrams I consider to tell "incomplete stories" and which are not macroscopically observable, The main reason is because such diagrams cannot obey macroscopic momentum & energy conservation except in trivial limits.

Because of the Diagram Fact combined with finite-volume mensuration lemmas, if diagram inputs and outputs are regarded as initially blurred over, i.e. confined within, known pseudoballs, then with any particular R>0 the series we are summing for the diagrams with N≥5 vertices always **terminates** even if we allow N→∞. Therefore, at least before taking the R→∞ limit, there is no longer any worry about Dysonian "series divergence," thus solving a huge foundational problem bedeviling old style QED.

But what about *after* we take the R→∞ limit? I believe (and offer nonrigorous arguments for why in the book) that the series will still **converge** even then, *provided* that:

i. We are doing this all in de Sitter, *not* Minkowski, spacetime,
ii. the dimensionless fine structure constant α>0 [whose measured value in our universe is α=1/137.035999084(21)] is sufficiently small. (I have not worked out exactly how small is "sufficiently small," but believe $|\alpha|<10^{-500}$ ought to be safe, and $|\alpha|<10^{-10^{300}}$ *very* safe.)

Intuitively, the reason this is so is related to the fact that de Sitter spacetime (unlike Minkowski), has a built-in finite large length scale, the "Hubble length," which in our universe is about

$$H \approx 1.4\times10^{10} \text{ lightyears} \approx 1.3\times10^{26} \text{ meters} \approx 8.4\times10^{60} \text{ Planck lengths.}$$

The bad effects of increasing R greatly diminish once R>H because of the classical fact that "you can't come back in" if you ever go outside the "de Sitter horizon." A devil's advocate could try to avoid this using Feynman diagrams whose vertices all are located spatially-near one another, but then you'll either run out of raindrops, or be forced to travel far in the ±t directions in which case enough |propagators| will diminish enough to assure convergence.

But (I hear you scream) what about summation using our universe's *actual* α=1/137.036, which is a hell of a lot greater than 10^{-500} and $10^{-10^{300}}$? That may be algorithmically accomplished to arbitrary user-specified accuracy by analytic continuation (if necessary) of the series-sum (regarded as a Maclaurin series in ascending powers of α) in the complex α plane outside its perhaps small, but positive-size, convergence disk. That technique had been unusable in old-style pre-cloud QFTs because of arguments that the radius of convergence of the series in the complex α-plane necessarily was exactly *zero*, so there is nothing for anybody to "continue." (The original such "no go" argument was published by Freeman J. Dyson in 1952, and I discuss many more such arguments in the book.) But **cloud solves the series-divergence problem**.

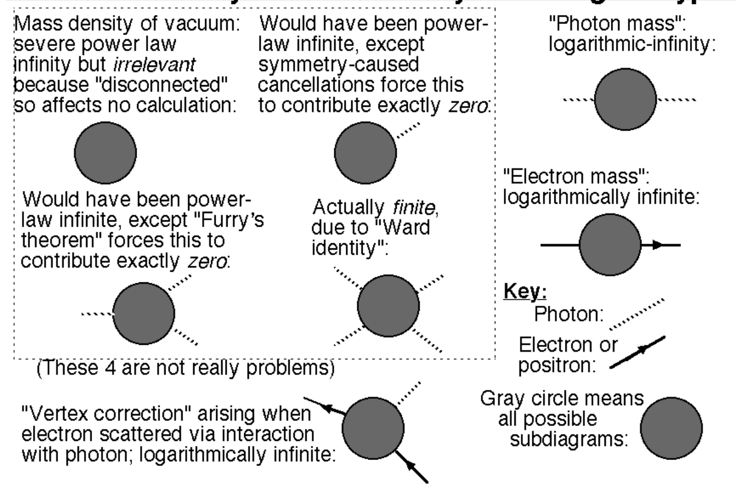
Now another huge problem that had bedeviled old style QED were "**ultraviolet infinities**," which in the cloud QED context would mean diagram amplitudes which often become infinite in the L_{brick}→0+ limit. Old-style QEDists had dodged those via two tricks:

I. "Renormalization" tricks which "shoved the problem under the rug." QED contains (according to the usual reckoning) exactly 3 different "fundamental infinities," see picture. What exactly they are, depends on the notation of that author, or the interpreter of QED. One reckoning calls the three potentially-infinite "renormalization constants" Z_1, Z_2, and Z_3. They respectively are related to

(1) the "running" fine structure constant, aka electron-photon-coupling constant, aka squared dressed charge, (2) "wave function renormalization," and (3) photon mass, aka photon self-energy, aka photon wavefunction renormalization. They then proved a theorem ("Ward identity") that $Z_1=Z_2$ whereupon there really are only two. A somewhat different reckoning regards the three fundamental infinities as

1. the dressed electron mass, aka electron "self energy." [Here "bare mass" means the mass of a hypothetical "free" electron, i.e. one not ever interacting with anything. Real electrons are "dressed" by their interactions with self-generated photons, which in turn can self-generate electron-positron pairs, etc etc, and when the mass of all that baggage is included we get the electron's larger "dressed mass," which is the quantity observed in physical experiments.]
2. the "photon mass" (potentially infinite but which, by theorem, actually is exactly zero).
3. the dressed electron charge.

The 7 conceivably-infinite QED Feynman diagram types:



In any case, everybody was well aware that it is unacceptable for a physical theory to predict each electron has infinite mass! The QEDists handled that by inventing an ingenious finite collection of algebro-graphical surgical "replacement rules" for Feynman diagram amplitude formulae. The purpose of these surgical formula-alterations was to convert any amplitude formula that would have yielded an infinity, into one that yields something finite, because, e.g, all the terms causing infinite electron mass get surgically removed and replaced by terms that, by design, yield the experimentally-measured electron mass $m_e=9.1093837015(28)\times10^{-31}$ kg! P.A.M.Dirac objected to this, complaining that "terms should be neglected because they are small, not because they are infinite and you wish they were small!" However, the attitude of the renormalized-QED pioneers S-I.Tomonaga, J.S.Schwinger, and R.P.Feynman (and Dyson, who explained why their three approaches actually all were equivalent) was that there was some true theory of physics, which they (and for that matter, all humanity at that time) was too stupid to know; and there was QED, which was *not* the true theory of physics, but clearly was somehow going far in the right direction. And somehow, in some unknown way, the true theory gets rid of those QED infinities and makes the electron mass and charge agree with their experimental values. Their *point* was that *despite* not knowing what that true theory was, you *still* could compute many numerical answers via the renormalization surgery-tricks, and they had to be the same answers as those the true theory would have given you (at least, the "same" to within the level of approximation that comes from ignoring all diagrams with more than N vertices; I call that "QED_N"). And when some such computations were (very laboriously) carried through, they yielded some of the most spectacularly precise theory-experiment agreements in the history of physics. This convinced the QEDists they were on the right track, so to hell with Dirac. Many even proclaimed that there was nothing wrong with renormalization and it was perfectly ok for fundamental physics to be based on it, and indeed things *should* be that way. But: (i) graviton physics is unrenormalizable, and (ii) the "Landau pole" is a logical self-contradiction in QED, so I cannot accept that.

II. The "summed energy of all zero-point vacuum modes" (which exist, say experiments on the Casimir effect and Lamb shift!) is unaffected by renormalization and still comes out infinite, but the QEDists simply **ignored** that and argued it did not matter since only Feynman diagrams with positive numbers of inputs and outputs can affect experiments, whereas (by definition) "vacuum energy" diagrams are precisely those with zero inputs and zero outputs. But it is disquieting, to say the least, that QED asserts that vacuum "ought" to have infinite – or even merely enormously large finite! – mass-density. Although that huge density ought to be exerting huge gravitational effects, experimentally those effects are tiny. And incidentally, QED's three renormalizable infinities, and indeed all renormalizable infinities in all QFTs, have, at worst, only power-of-log severity for any particular diagram. In contrast, the vacuum energy has far worse – power-law infinite – severity.

Really, neither I nor II were satisfactory, but they did successfully serve as stopgap measures to allow computations to be made in the era before any actually-satisfactory theory (cloud QED, I hope!) could be invented.

I claim that cloud QED **no longer needs renormalization to get rid of UV infinities.** With cloud, renormalization still could be employed as an ingenious algorithmic trick to get more accuracy with less computational work (at least in some precision-regimes for some calculations), but is not present in the fundamental underlying theory.

Why does cloud abolish UV infinities? The book gives two quite different reasons (both fall short of complete rigor, but seem adequately convincing):

1. The "Debye/Nyquist argument"
2. The "Feller law of large numbers" (FLLN) argument.

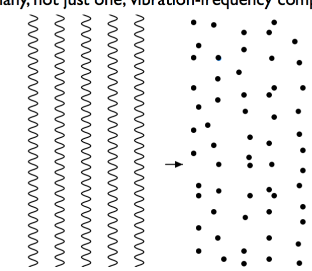
Either alone seems to suffice, but having two makes this very convincing. Let me sketch them.

Debye. Peter J.W. Debye (1884-1966) in 1912 published his famous model of the thermodynamics of a large class of solid substances. Specifically, his model is intended to work best for crystalline, electrically-insulating, non-magnetic, strongly chemically-bonded materials with no solid-solid "phase transitions," e.g. diamond-phase C, Al_2O_3, KCl, and CaF_2. In his model there are N point-mass atoms regarded as embedded in an elastic medium whose mass is negligible by comparison.

> "Negligible" because Debye wants all the kinetic energy of the material to arise from its atomic motions. And it actually is not logically necessary for the "medium" to exist, in the sense that *any* model of atomic vibrations (including *not having any* model, i.e. all atoms magically vibrate independently) yielding Debye's same mode-density as a function of frequency, would yield the same results. Further: *more correct* mode-densities than Debye's, e.g. based on computer modeling of each material's crystal lattice – but still using Debye's unaltered "total #modes = 3N" cutoff assumption – empirically *outperform* plain Debye.

Thermal excitations cause the atoms to vibrate. The key ingredients Debye postulated in this model are (i) he assumed that the vibrations are describable as a linear combination of "modes" with "mode density" in frequency space that is proportional to frequency *squared* – i.e. exactly what would have been true for a uniform-mass-density elastic medium, except that (ii) there is a **mode cutoff** at the "Debye frequency," causing the total number of modes to equal 3N. No vibrations at any frequency higher than Debye are permitted! Of course Debye was aware his model is an idealization; in reality, e.g, the atoms are linked by *non*linear springs hence do not really obey the classical wave equation. So Debye's validity must be assessed via experiment. My book reviews this and finds that Debye model predictions of, e.g, heat capacities, are obeyed well in experiments across a large set of materials and large range of temperatures. Unfortunately it has not been obeyed well in experiments so far on *amorphous* solids e.g. SiO_2, nor on certain poorly-bonded solids such as elemental I_2 and N_2. But I conjecture that the problem in those cases has simply been that the experimenters failed to cool to temperatures cold-enough to "freeze out" certain classes of thermal excitation that were *not* the vibrations modeled by Debye and which provide extraneous additional heat reservoirs. I would like for experimenters to try harder to resolve that.

My point is that "raindrops" in cloud QED are highly mathematically analogous to "atoms" in Debye's class of solids, with the "vacuum modes" of QED being analogous to Debye's elastic vibrational modes. The main differences are first, that for Debye the wavespeed is the speed of sound, while for QED it is lightspeed; and second, Debye's atoms reside in 3-dimensional space – or if you regard it as (1+3)-dimensional spacetime then they each are not *points* but rather Einsteinian "worldlines" (somewhat wiggly lines, in view of the vibrations) – whereas cloud-QED raindrops really are points in (1+3)-dimensional space*time*. The first difference is trivially handled. To handle the second, imagine replacing Debye's atom-worldlines by *dotted lines*. Suppose the dot time-spacing is epsilon plus the Nyquist rate corresponding to the Debye frequency F_{deb}, namely 2 dots per cycle-time per worldline. Then, even if Debye's atoms were regarded as existing only at the precise moments their worldlines encountered those dots, that *would not matter*. "Would not matter" because by Nyquist's theorem from bandlimited communication theory, the full vibrational history. i.e. each full undotted worldline, would then be uniquely reconstructible from the locations of its dots alone; but if any rate below Nyquist had been used then would not be reconstructible. Although the simplest and best known version of Nyquist's theorem pertains to *uniform* dot-spacings, there also are many known "irregular sampling" versions of that theorem – in particular, some which work (with probability=1) for Poisson-random dots. The "Nyquist dotted-line trick" thus interconverts Debye's scenario ↔ the cloud scenario.



"Dotting" Debye worldlines
[Except our dot rate here is considerably below "Nyquist rate"; and Debye atoms would have many, not just one, vibration-frequency component]

For this reason, any physicist willing to accept both the Debye-model's mode cutoff, and Nyquist's theorem, must accept that cloud QED naturally also forces an ultraviolet cutoff. Specifically (in the model based on the classic scalar wave equation with 3 modes per raindrop, i.e. what Debye was considering), all frequencies above

$$F_{cutoff} = (\rho_{rain} c^3)^{1/4} / 2$$

are cut off. (Other kinds of wave equations and waves would yield essentially the same formula, but perhaps with somewhat different constants.) And note that this same numerical frequency limit is agreed by all special-relativistic observers to happen, *despite* the fact that, due to Doppler shifting, any moving observer will disagree with you about the frequency of, say, some laser beam. Observers Amy and Bob both agree on the value of F_{cutoff} and both agree everything is a linear combination of modes with frequencies below that cutoff; but do *not* agree on what that linear combination is; and Amy's "mode #5" is not the same as Bob's "mode #5."

Presto: It was already well known to QEDists that any such UV cutoff naturally causes the renormalizable QED infinities, such as electron mass and charge, to become finite in any diagram, with no need anymore for renormalization. (This also gets rid of QED's "Landau pole" self-contradiction.)

Feller. Next, for something completely different, consider the prototypical logarithmically-infinite integral $\int_{0<x<1} dx/x$. Suppose we naively attempt to evaluate this integral via P-point Monte Carlo integration. Then, obviously, that is going to deliver (with probability=1) a *finite* answer. More remarkably, and what is considerably less well known, is that this Monte Carlo randomized answer is going to be *highly reproducible* across multiple such Monte Carlo experiments. More precisely, for any particular ε>0, no matter how small: for all large-enough P the probability will exceed 1-ε that the P-point Monte Carlo answer will lie within relative error ε away from a certain logarithmically-growing function of P, which for this integral is roughly 1.76+ln(0.27125+P). This is just one instance of a very general theorem that I call "**Feller's law of large numbers**" published in 1936/7 by William Feller (1906-1970). It works for a wide class of finite and infinite integrals, and the dividing line where FLLN stops assuring relative error→0 with probability→1 corresponds quite closely to what physicists call "power-law infinities." For those FLLN does not work; but for any infinity less-severe than any power law, it does work. At present the FLLN is much less famous than the "weak" and "strong law of large numbers" but I now claim that it plays a central role, arguably even *the* central role, in cloud-QFT physics, essentially because raindrops *are* Monte Carlo integration points, and there are huge numbers of them. My point is basically, that old-style QEDists thought physics performed certain integrations, then encountered the problem that those integrals were logarithmically infinite. My claim with cloud QED is "NO: actually, physics performs *Monte Carlo integrations*, i.e. summations using random raindrops", and usually with only a finite set of such raindrops, too. The difficulty in attempting to apply the FLLN to, say, the integration of some V-vertex diagram over all possible spacetime locations of its V vertices (4V-dimensional integration) is that is it not obvious what Feller's "P" ought to be. Does P equal the number N of raindrop-vertices in our spacetime region? Or (what I would contend) shouldn't it be something more like N^V, because you really are integrating over V-*tuples* of raindrops, and there are about N^V such tuples? The trouble with the latter contention is that these N^V tuples are not all independent of each other (unlike the N raindrops, which are), so that, rigorously speaking, Feller's law is inapplicable. The question then is whether they nevertheless "act independently enough" to cause Feller's theorem to "work well enough" using $P \approx N^V$ to accurately describe reality. I tried to answer that question via computer experiments with certain multidimensional test-integrals, some logarithmically or log-power infinite, and designed by me to resemble QED integrals, but also to be considerably easier to understand. These tests indeed exhibited the desired kinds of behavior, and indeed for the purpose of relative-*error* estimation it was found best to regard P as much nearer to N^V than to P=N; although for the other purpose of estimating the *value* of the Monte Carlo "integral," it often is best to regard P as nearer to N than to N^V. (I call that "hybrid" or "two-faced" Feller.) So this is nonrigorous, but it appears based on my computational experiments that a Feller-like law really should hold, and hence that QED diagrams when "integrated" via the cloud-QED raindrop summation process will indeed return highly reproducible numerical answers with high probability, which involve the "logarithmic infinities" getting automatically replaced by finite values that well-approximate certain logarithmically-growing functions of N. And because of the tameness of the log function, these values are not merely finite, but indeed perfectly reasonable.

So Debye-Nyquist and Feller take care of QED's renormalizable diagram-infinities without need for renormalization.

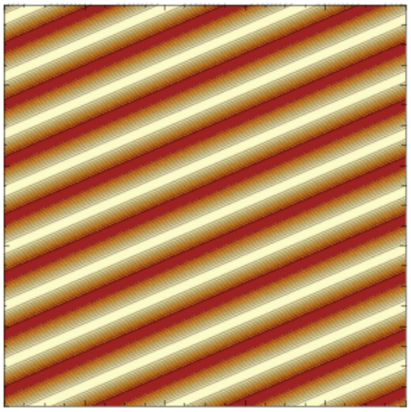
But the nonrenormalizably-infinite **vacuum energy** is harder to tame. First of all, the Debye-Nyquist "UV mode cutoff" does render the vacuum energy *finite*. But if that were all we had, it would not be good enough because the vacuum mass-energy |density| would still be expected to be very *large*, e.g. of order Planck scale, e.g. in human units $\approx 5\times10^{96}$ kg/meter^3. That would conflict tremendously with gravitational experiments. (S.Weinberg called this the "cosmical constant crisis," CCC.) We can do much better by proposing that there are a finite set of new, as yet unknown to the "standard model," bosons. The reason these extra bosons have not yet been detected is that they are unstable and have higher mass-energies than our accelerators can reach. These new particle-types cause the number of boson mode-flavors at any given wavelength to *equal* the number of fermion mode flavors. The point: it has been known ever since Dirac that boson "zeropoint" vacuum modes have positive energies, but fermionic modes have negative energies. We in this way make the two automatically approximately *cancel* to zero. Call the energy, or mass, or angular frequency (in Planck units, these all are equal since c=1 and $\hbar$=1), of the mode-cutoff "א." Then (in Planck units) the summed "zeropoint" mass-energies of all the modes in an **L×L×L box** of vacuum (L measured in Planck mass-units), would have been a number of order $(L\aleph)^3$ without this cancelation. But with it, it instead merely becomes a number of order

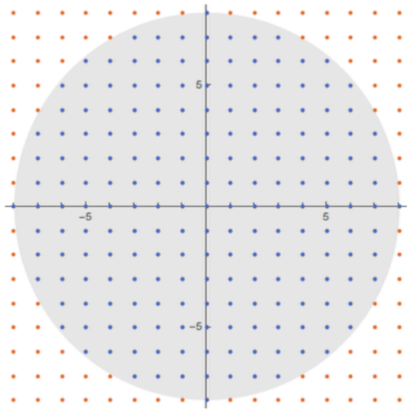
$$0\cdot(L\aleph)^3 + 0\cdot(L\aleph)^2 + \text{SpectralRoughness}_3(L\aleph) + L\aleph\,[\textstyle\sum_f (m_f)^2 - \sum_b (m_b)^2] + [\text{terms involving } (L\aleph)^e \text{ for exponents } e\le 0].$$

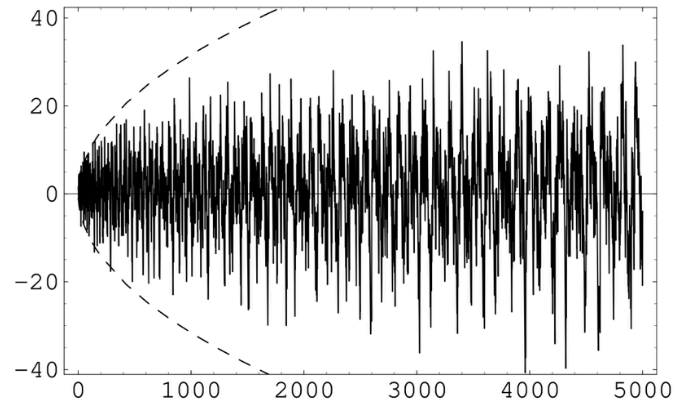
where the $(L\aleph)^2$ term would have had a nonzero coefficient if there were Dirichlet or Neumann boundary conditions on the box walls, but with periodic boundary conditions, i.e. no boundaries, it is 0; and the sums are over fermion ("f") and boson ("b") mode-flavors, and where m_f denotes the rest-mass of fermion f, and m_b the rest-mass of boson b. Here "$\text{SpectralRoughness}_3(x)$" is a "rough" pseudorandom-noise-like function which crosses zero infinitely many times and has RMS amplitude of order $x^2\log(x)$ when $x\to\infty$. Indeed, a function very related to $\text{SpectralRoughness}_3(x)$ has been proven to change its sign at least once in every x-interval of some constant length, and empirically $\text{SpectralRoughness}_3(x)$ actually changes sign unboundedly more often than that when $x\to\infty$ (although this claim is based on computer experiments, not proven).

By (if necessary) adding a finite set of extra high-mass unstable fermions and bosons to the standard model, and choosing their rest-masses just right ("fine tuning"), we could, if desired, also force the [$\sum_f$-$\sum_b$] term to equal zero, although with the presently known particles and their presently known rest masses, it does not equal zero. But those experimental rest-masses were "dressed" values, and based on SM calculations of how they "run" by F.Jegerlehner in 2013, it actually looks like this equation actually is satisfied by their *bare* masses. Anyhow Jegerlehner estimated this zero crossing occurs at energy scale $7\times10^{16\pm1}$ GeV, i.e. Planck energy divided by 17-1700.

In any case, it is not necessary either to rely on Jegerlehner or to fine-tune the m's. At worst, extremely crude tuning is all that is needed, with the known particle mass values already being adequate. That is because the $\text{SpectralRoughness}_3$ noiselike term already dwarfs the [$\sum_f$-$\sum_b$] term by an unboundedly large factor in the Lℵ→∞ limit. And as we'll soon explain, that roughness will solve the "cosmical constant crisis."







What exactly is "spectral roughness"? It has two causes. The first is the "smooth geometry cause" which works even in old fashioned (no cloud, no raindrops, plain Euclidean) geometry. To enable drawing pictures, let me explain this in only 2 space dimensions. Any mode in an L×L box is described by two integers, say a and b (left picture shows mode with a=3, b=**-**7), saying how many wavelengths fit in the horizontal and vertical directions in the box. In Planck units the energy of this mode is $E=(a^2+b^2)^{1/2}/(2\pi L)$.

The number of modes below any given energy cutoff therefore equals the number N(r) of integer lattice points lying within a circle of radius $r=2\pi LE_{cut}$ (middle picture). Obviously $N(r)\approx r^2\pi$. The *error* in that obvious approximation, call it $Y(x)=N(\sqrt{x})-\pi x$, behaves very irregularly, see plot in righthand picture. [The dashed parabola is $y=\pm\sqrt{x}$, which is known to provide upper and lower bounds on Y(x). Pictures drawn by Eric Weisstein.] This irregularity is what I mean by "roughness." Now actually we want the *three*-dimensional version of this (L×L×L box, lattice points in 3D ball) and we want not to *count* the lattice points in the ball, but rather to *sum their vector-lengths* to get the total of all mode energies below cutoff. The same sort of spectral roughness occurs for that function. We alternatively may regard it as a function not of "x," but rather of L, or F_{cutoff}, or of the number N of modes. And it's more realistic to consider a generic *parallelipiped* rather than cubical box, whereupon we have lattice points in an *ellipsoid* not ball and then $\text{SpectralRoughness}_3(x)$ has order x^2 not $x^2\log(x)$. Regardless which of those ways you view it, you get roughness.

The second cause is the fact that we've actually got raindrops, and their number governs the value of the cutoff, e.g. for an L×L×L box in Planck units, for duration=L, containing N raindrops, our Debye-Nyquist cutoff frequency was $F_{cutoff}=N^{1/4}/(2L)$. Here N is *random* and varies typically by $\pm\sqrt{N}$. This variation also causes "roughness." As it happens, both causes of roughness generate amplitudes of the same orders. The fact we have two causes, both yielding the same conclusion even if the other line of argument self-destructs, gives me high confidence in that conclusion.

This spectral roughness suffices to cause a "**gravitational feedback process**" continually driving the mass-energy of our box of vacuum toward 0. That is because: If it were nonzero, huge gravitational forces would arise, which would shrink or expand the box size L by a tiny amount (a small fraction of a Planck length suffices) until the $\text{SpectralRoughness}_3$(Lℵ) reaches an "attracting 0." [The $\text{SpectralRoughness}_3(x)$ function has two kinds of zero-crossings in 50-50 ratio: stable aka attracting causing "negative feedback", and unstable aka repelling causing departure from there.] Hence L continually "self adjusts" to *cause* the vacuum's mass density to be on average 0. Although I described this mechanism in an artificial global model of the universe as an L×L×L flatspace box of vacuum, presumably in reality in unbounded de Sitter spacetime, this feedback mechanism operates locally everywhere all the time.

This feedback mechanism explains why the vacuum experimentally has mass-density very near zero – solving yet another devastating foundational problem with prior QFTs. But Weinberg's "*second* cosmical crisis" is the problem that in our universe, the

Einstein cosmical constant Λ_{ein}=1.01(4)×10^{-35} $second^{-2}$ is observed to be very small but *not* zero. An obvious reason that must happen is because cloud QED was by assumption set up in a de Sitter spacetime "background geometry", *forcing* Λ_{ein} to be nonzero and with "repulsive sign." And the universe had to be that way, because only de Sitter solves QED's series-divergence problem. A second is that, although this feedback mechanism can attain good accuracy, it cannot be perfect (although this presumably improves arbitrarily with longer measurement times).

Summary so far. I now have described to you what cloud physics is, and how and why it solves all seven major huge foundational problems that bedeviled all prior physical QFTs: **(1)** generic series divergence, **(2)** UV infinities, **(3)** Landau pole, **(4)** Weinberg cosmical constant crisis, **(5)** second CCC, plus predicting correct Λ_{ein} sign as bonus, **(6)** "weirdness," "measurement," and position-basis-primacy issues underlying all quantum mechanics. We've also shown – unlike every prior physical QFT – that **(7)** cloud-QFT is an *algorithmic* theory, i.e, one capable of predicting any experiment to arbitrarily great user-specified accuracy with arbitrarily great user-specified confidence, provided you are willing to run your computer (Turing machine equipped with random bit generator) long enough. In contrast, for most computational tasks, no QFT before now has ever been capable of guaranteeing any accuracy bound whatsoever, and therefore in principle none of them ever met Karl Popper's "falsifiability" criterion for whether something is "science." Cloud QED is the first ever to meet that test in principle – although admittedly just barely in the sense that my algorithms are extremely slow. (I have made virtually no attempt to speed up the algorithms. All I aimed to do was to show for the first time that suitable randomized physics-simulation algorithms *exist*.)

The fundamental operations (propagation and interaction) in cloud QED are simply time-evolution of the usual PDEs by using their Green's functions, with the only change being that instead of *integrating*, physics raindrop-*sums*, thus performing a Monte Carlo approximate integration. Due to the enormous number of raindrops, cloud and old-style physics should be indistinguishable at all levels of precision yet reached by experimenters... at least if we generously ignore such blatant discrepancies as electron and vacuum masses being "infinite." Therefore **(8)** all experimental evidence ever gathered supporting old-style physics in fact supports cloud, plus there is additional blatantly obvious experimental evidence (e.g. non-infinities, non-weirdness, positional basis favortism, entropic "arrow of time") supporting cloud but refuting old-style physics.

So we all now have a whole new world to explore. And I have only begun that exploration.

Now that we have cloud-QFT theory... Let me show you its features!

The standard model had incorrectly claimed that **neutrinos** were massless. But it now is known that they all have small, but positive, masses. (There are several possible ways to repair the SM to incorporate that, but it currently is not known which one is right.) This "huge surprise" is *not* a surprise with cloud-QFT, because it **logically forces all fermion masses to be positive**, and indeed I've derived a lower bound $\geq(2H)^{-1}$ for them in Planck units, which in human units is $\geq 1.4\times10^{-69}$kg ≈ 8×10^{-34} eV/c^2.

The astronomical observations showing Einstein's **cosmical constant Λ_{ein}** is nonzero and repelling in sign, were another "huge surprise," which again actually is a "logically forced prediction" of cloud QFT.

With cloud all lengths, times, areas, 3-volumes, and 4-volumes are **inherently imprecise**. One reason for that is that for a 4-volume V, containing in expectation $N=\rho_{rain}V$ raindrops, there actually will be Poisson-random noise in that count, of order ±√N. That is a sense in which V (if measured in Planck units) has inherent uncertainty of order ±√V. If V were an L×L×L×L hypercube, that is equivalent to an uncertainty of order ±1 in areas $A=L^2$, and an uncertainty of order ±1/(L+1) in lengths L. Also note, if we had L_{brick} of order 1 Planck length, that would cause "blurring" of inter-raindrop pseudodistances L, again by amounts of order ±1/(L+1).

The orders of those inherent imprecisions happen to coincide with thought-experiments in the book about the best possibly conceivably achievable precisions for length, time, and area measurements. In other words **it had to be that way** and something like cloud therefore is, and always was, logically forced upon the structure of spacetime; and cloud is the **least-radical possible** change to old notions.

Cloud set in de Sitter spacetime provides **triply-special relativity**. To explain: It historically was a great surprise that the speed of light c is observer-independent. This initially seemed logically impossible and caused a lot of confusion. However, as every special-relativity fan knows, Einstein showed that it *was* possible, because each observer has a different private notion of space yardsticks and clock times, and this all happens in just the right way to make it all self-consistent. I'll call that "singly special" relativity. But now, with cloud, we also have a constant microscopic length scale $(\rho_{rain}/c)^{1/4}$ of order the "Planck length" which is regarded as the same by all observers. Naively, that seems impossible since a moving observer thinks lengths are shorter. But evidently it is possible. Call that "doubly-special relativity." And everybody already knew there *is* an invariant Planck length in physics, so therefore something like cloud is logically forced. Finally, there also is a cosmologically-large fixed length scale, the Hubble length, built into de Sitter geometry, which again all observers agree upon, albeit for a completely different reason. That's "triply-special relativity."

Although the way Einstein resolved the c-constancy apparent-paradox was "smooth," i.e. Minkowski spacetime is a smooth pseudometric, one can argue using the known full classification of low-dimensional Lie groups that there cannot be any smooth metrical solution to the triple-relativity "paradox." Therefore something discontinuous like cloud was logically forced.

"**Supersymmetry**" (SUSY) is an amazing postulated new symmetry of physics which interconverts fermion ↔ boson modes. It underlies "supergravity" which in turn underlies "superstring theory." All that is **wrong**. I have arguments cloud logically forces SUSY **not** to happen in our universe. This explains the "surprise" (for some experts I quoted, decade after decade of utterly stunning, large-financial-bet-losing surprise) of continued lack of any evidence for SUSY in decade after decade of accelerator experiments. One of the main clues inspiring proponents to retain hope for SUSY was the fact that in the MSSM (minimal supersymmetric extension of the standard model) allegedly-appropriate versions of the fundamental α coupling constants – which due to SM particles all being "dressed," are *not* constants but rather "run" – all attained almost the same value $25.35 \le \alpha^{-1} \le 25.65$ at an energy scale of approximately 10^{16} GeV, corresponding to a length scale of about 1220 Planck lengths. However, with cloud-SM without SUSY, I argue that allegedly-appropriate versions of the weak, strong, electromagnetic, *and* Higgs, *and* gravitational coupling strengths all *agree* ($\alpha^{-1}=52\pm5$) to within ±10% at about 7 Planck lengths. This meet, if genuine, could be regarded as all these forces all being the *same*, or anyhow the same strength, at this energy-scale, which we then would regard as their "bare" values. It would simplify physics greatly if there were **only *one* universal all-purpose bare coupling constant**.

Casimir forces are a QFT prediction which, although finite and in agreement with experiment in certain atypically-simple high-symmetry mirror geometries (e.g. constant curvature), unfortunately predict infinite forces for generic geometries (obviously in vast disagreement with experiment). This problem was pointed out by D.Deutsch & P.Candelas in 1979. The built in mode-cutoffs from cloud abolish their infinities.

Hawking entropy of black holes is a phenomenon everybody is reasonably sure is genuine: Black hole horizons have an entropy of 4ln2 bits per Planck-area unit. This has lacked any *microscopic* explanation. This includes in superstring theory, where they allegedly did explain such entropy in certain unphysical geometric scenarios, then hyped that so-called achievement to the moon, *but* after decades of work still have remained unable to do it for (1+3)-dimensional non-extreme Kerr black holes, i.e. the kind actually present in our universe. With cloud, the Hawking entropy "surprise" is not a surprise, once again it is a "simple, logically forced prediction" which gives the right order of magnitude, and should enable deducing the exact value of ρ_{rain}. Essentially, at any horizon the question of whether raindrops lie inside or outside the horizon, is crucial and produces about 1 bit of entropy per raindrop whose inside/outsideness was a priori highly uncertain.

What was even more mysterious and profound-seeming than Hawking black hole entropy was the **Bekenstein bound** (sometimes called "holographic upper bound") on the entropy of *anything*. This states that if you mentally enclose any physical system whatever by a sphere, then its entropy is ≤4ln2 bits per Planck surface-area unit for that sphere. This was argued by Bekenstein using a "proof by contradiction" – if some system could have entropy exceeding said bound, then by "dropping it into a large-enough black hole" you could reduce total entropy, violating the second law of thermodynamics. The trouble with such proofs by contradiction is they are "nonconstructive." They give us no clue what, microscopically, prevents all physical systems from having more entropy than the Bekenstein bound. And it sure seems as though most physical systems have almost nothing to do with the surface area of some imaginary mental sphere surrounding them! Bekenstein's bound played a very important formative role in the arguments in my book for why cloud QED had to be invented and had to happen. So it now is time for cloud QED to return the favor by providing a microscopic explanation for Bekenstein. But first I must discuss

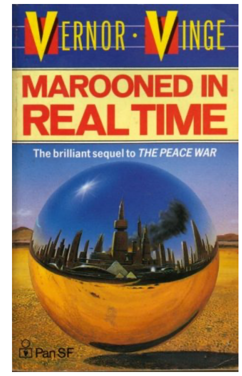
Entropy in the cloud universe. It naively might seem obvious that the "bulk entropy" (of the information involved in encoding all the raindrop locations in a given 4-volume) should vastly outweigh all other kinds of entropy. But looking deeper: I believe this sort of entropy actually has almost no physical importance! It is just a big added constant. (Or big added pre-known function of time, and *only* of time, in de Sitter spacetime.) The reason it is "constant" is the rest of physics does not affect raindrops. They still have the same 4D number density and statistics regardless of whatever else happens. Since only entropy *changes* and transfers have physical importance, raindrop-location entropy normally is irrelevant.

The entropy of the cloud vacuum at temperature T is actually precisely predicted, in closed form, by our repurposed "Debye-Nyquist" model. Essentially, Debye already did the calculation in 1912. The result is that the entropy per unit 3-volume is proportional to T^3 at low temperatures T ("ideal photon gas"), but after T rises to the Planck temperature, that cubic growth ends; and thereafter the entropy density behaves like a constant (of order 1 bit per Planck volume unit) times a factor growing only logarithmically with T.

In the case of black hole "inside or outside" entropy it is obvious (obvious to anybody familiar with Hawking radiation derivations, anyhow) that the raindrop locations near the horizon *matter*, i.e. tremendously affect (far more than anything else) the nature of the Hawking radiation, and thus associating that entropy with the Hawking temperature was an entirely reasonable thing to do. Black holes give physics access to a "surface term," which is far less than the "bulk," but seems the most you can access. Or is it?

Predicted "temperature floor." The only obvious way to access the vastness of bulk raindrop entropy would be to create more space, thus creating more raindrops. The Einstein cosmical constant Λ_{ein} is often associated with an "effective mass-energy density of the vacuum"

$$\rho_{vac} = \Lambda_{ein}/(8\pi G) \approx (6.0\pm0.3)\times10^{-27}\ \text{kg/meter}^3 \approx (3.6\pm0.2)\ \text{amu/meter}^3.$$



And arguably each quantum mode (below the Debye/Nyquist cutoff) is associated with entropy, e.g. order 1 bit worth of entropy (e.g. from raindrops and modes existing/not). If so, in view of the definition of temperature $k_B T=\partial E/\partial S$ where k_B=1.380649×10^{-23} Joule/Kelvin is Boltzmann's constant, E is energy, and S is entropy (in nats) of a physical system, cloud QFT predicts the existence of a "temperature floor" of order

$$T_{min} \approx c^{11/4}\ (\rho_{rain})^{-3/4}\ \Lambda_{ein}\ (8\pi G k_B)^{-1} \approx 4\times10^{-(87\text{ to }98)}\ \text{Kelvin};$$

it is impossible to cool anything colder than this.

Now we are ready to **explain Bekenstein microscopically.** Suppose the sphere containing your physical system was actually a genuine "magic impenetrable wall," aka perfect mirror, isolating it from the rest of the universe.

> Something like such a magic wall was the central idea in certain Vernor Vinge science fiction novels. Vinge called them "bobbles" and supposedly they could be created by some magic future technology. Inside a bobble, time stopped (not the case for our walls, only for Vinge's bobbles), and then after a certain amount of (external) time the bobble-wall would magically vanish, restoring the connectivity of the universe, so, e.g. anybody trapped in a bobble would think he'd suddenly been transported 1782 years (or whatever) into the future.
> Unfortunately, Vinge did not seem to realize that his bobbles, being perfectly rigid, would violate special relativity. If you tapped one side of a bobble, the vibration would transmit instantly to the other side, faster than light, which as far as the right moving observers were concerned, would be transmitting vibrational information backwards in time. Since Vinge's largest bobbles were only ≈10 miles in diameter this would only violate causality by at most about 50 microseconds, but still.

But what Vinge definitely did not realize is that any such "magic wall" would be associated with *tremendous* "surface entropy" of the raindrop inside/outside kind, in fact meeting (perhaps up to a constant factor) the Bekenstein bound. Therefore such a wall, if one ever could be obtained, definitely would *not* be suddenly and silently vanishing, since that would hugely violate the second law.

The alert reader should now be complaining: "Your argument did not show Bekenstein's *upper* bound, it merely showed a *lower* bound which would meet that upper bound if it were possible to construct magic spherical perfect mirrors. And furthermore, since that surface entropy is of order R^2 for a radius-R (in Planck units) sphere, it seems obvious that I can, by making R large enough, far exceed that by, e.g. filling the sphere with a crystal whose atoms each could be of 2 isotopes, thus getting entropy growing like R^3."

That complaint is wrong. The problem is that is it not possible (Schwarzschild radius) to put a mass exceeding R/2 Planck masses inside a ball of radius R Planck lengths. If you try, it will collapse into a black hole. Note, this grows only *linearly*, far slower than R^2 and R^3. So you cannot fill your sphere with atoms – and more importantly, you cannot fill your sphere with *anything* – to beat the Bekenstein bound. That is because we know the greatest entropy possible at large temperature T is upper bounded by the entropy of an ideal photon gas (up to a constant factor, anyhow); and by the repurposed Debye calculation, the total mass-energy of such a gas grows proportionally to T^4 times the volume of the container (for T below 1 in Planck units). Meanwhile its entropy grows proportionally to T^3 times volume. You cannot reach T of order 1 or above in Planck units because that would collapse your radius-R sphere (if $R\gg1$ Planck length) into a black hole. In short, given the $M\le R/2$ mass limit and the volume $4\pi R^3/3$ of the ball, the entropy of any stuff filling the ball necessarily will be $O(R^{1.5})$, which is *sub*quadratic. So actually, the Bekenstein bound usually is very weak. All physical systems with $R\gg1$ have much smaller entropy than the Bekenstein bound unless they are black holes or are equipped with magic mirrors.

An objection to cloud QFT is its alleged **lack of symmetry**. Plain Minkowski and de Sitter spacetimes are highly symmetric objects. E.g. Minkowski enjoys rotation, translation, and Lorentz-boost symmetries. Space-translation symmetry is responsible (via Noether's theorem) for momentum conservation in physics. Similarly, time-translation symmetry yields energy conservation, and rotation symmetry yields angular-momentum conservation. Once you put random raindrops in, these exact symmetries disappear. Oops.

Let me reply. First of all, the *whole* of cloud QFT, i.e. including *both* the interaction and propagation parts, *and* the separate pseudo-radioactivity Poisson process that continually generates raindrops, is exactly symmetric under the full group SO(3,1) of symmetries of de Sitter spacetime. The lack of symmetry only arises if you just consider the first part of the picture without the other two.

Second, the PDEs obeyed by propagators all have energy and momentum conservation built in. So *propagation*, if considered alone, obeys these conservation laws.

Third, cloud arguably is *way more symmetric* than old-style QFT. That argument depends on the use of symmetric "bricks." E.g. if we had 3-sphere bricks, then the rotation group SO(3) of a sphere would be an additional symmetry of everything beyond those available in old style QFTs. One could even argue that *all* bricks could be independently rotated, i.e. $SO(3)^N$ for N bricks, which is a *vast* amount of extra symmetry. But I must admit I'm unsure how legitimate it is to count that, given that cloud QFT is only done in an $L_{brick}\to 0+$ limit.

Fourth – and now I bring down the hammer – translation symmetry of Minkowski spacetime, and consequent momentum and energy conservation, had manifested via the fact that solutions of fundamental free-propagation equations (e.g. Dirac, Maxwell, Klein-Gordon, etc) may be Fourier-decomposed into plane waves, which are momentum-energy *eigenstates*; and those form a complete basis for wavefunctions in physics.

> Incidentally, if all particles in the entire universe had been set up initially in momentum-energy eigenstates (or in a rotationally-symmetric state) then according to pre-cloud QFTs the universe would retain translation (resp. rotation) symmetry forever. This refutes any delusion some might have had that those QFTs somehow in some mysterious bullshit way, yield primacy for the position basis and cause positional localization.

And any Fourier coefficient may be expressed as a certain integral (the "Fourier transform"). Well, with cloud, if you compute Fourier integrals via *Monte Carlo "integration"* i.e. raindrop-summation, then you get exactly the same answer because Monte Carlo integration (for suitable classes of function-integrations), with probability=1 yields the exact same answer as genuine integration whenever there are infinitely many sample points. So any signal sampled on raindrops, has the same Fourier decomposition. And then each of those Fourier modes still propagates according to the usual Lorentz-invariant partial differential equations such as Maxwell that govern the "propagators." The modes *below the Debye-Nyquist bandlimit* form a complete basis for wavefunctions *sampled on raindrops*. Therefore notions of momentum and energy conservation still happen. Compare with old-style QED: there momentum and energy conservation could be violated, and are violated, at Feynman diagram vertices in position space; it is only *after integration* of those vertices over all spacetime that those conservation laws are restored, via wavefunctions "interfering out" in regions which would have caused conservation-violations. With cloud, the same thing happens, and hence we do have violations microscopically-locally; but globally, to the extent Monte Carlo and genuine integrals agree, those violations are removed. Similarly, angular momentum is no longer conserved inside any finite-diameter measurement region during any finite time, but is conserved to greater and greater accuracy the longer you measure it.

Some readers may prefer another way to look at this. Suppose for a contradiction that cloud-QED really did violate energy and/or momentum conservation, e.g. tended to make things "lose momentum." Well, the problem with that contention is that cloud-QED is manifestly Lorentz invariant if set in Minkowski spacetime – so in the view of a different Lorentz observer, those things had to be *gaining* momentum! Cloud QED cannot favor any one observer over any other; that is just a mathematical fact. So this so-called "loss" or "gain" always is unbiased, i.e. always on average must be zero as regarded by every observer.

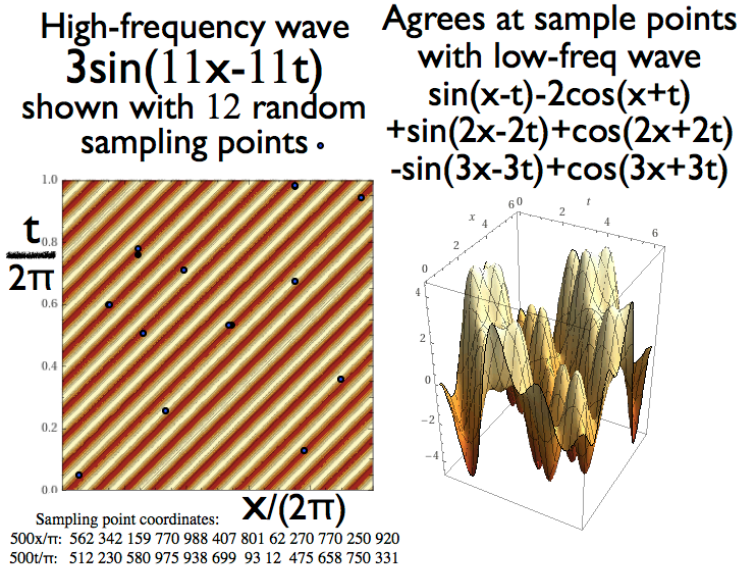
A related issue is **unitarity**, mainly meaning probability conservation. Recall that for any Q and R with $0\le Q<R$ the set of points X with $Q\le|PsuDist(X,A)|\le R$, where A is any particular fixed point, has infinite 4-volume, hence contains infinitely many raindrops. Since propagation from source-raindrop A is a function *solely* of PsuDist(A,X), the cloud-universe, viewing any such propagation via raindrops only, with probability=1 thinks that the integral over any pseudodistance interval (no matter how tiny) of the propagator, or its |square|, exactly equals the old-style integral. So again, via the theorem that Monte Carlo "integrals" exactly equal genuine integrals if we have infinitely many sample points, we still expect **exact probability conservation**, corresponding Noetherishly to exact "gauge invariance."

Cloud still enjoys, e.g, exact lepton number conservation, and hence **charge conservation**.

The second thing unitarity did to old-style quantum physics was it made physics time-**reversible** in the sense that the past may be deduced deterministically from the future equally well as the future may be deduced from the past, with no "information loss." Unitary time-evolution is a 1-to-1 invertible nowhere-expanding nowhere-contracting map between past↔future states. With cloud-QFT that still is true *provided* all raindrop locations throughout all time are regarded as exactly known to all. However, in reality, nobody knows them. They are random. Therefore the unitaritude of cloud QFT is only valid is an unrealistic sense. It is good enough to assure probability conservation, but the "no information loss" and "determinism" claims both cease to be valid. **Entropy now can increase**. With old style QFT, it never could. We experience an "arrow of time."

If you were to take the universe "now" and suddenly magically reverse time, parity=chirality, and all charges ("CPT symmetry") then old style QFT contends everything would then "run backward" to regenerate the past, with entropy then seemingly decreasing. e.g. broken glass bottles reassembling themselves, rubber balls bouncing higher and higher, old people un-dying then getting younger, etc etc. (This thought-experiment refutes any bullshit delusion some physicists had that entropy increase somehow was a consequence of their pre-cloud-QFT laws of physics.) With cloud QFT that also would happen if all the raindrop locations remained the same in the backward run as in the forward run. And the QFT part of cloud QFT still enjoys CPT invariance. *However*, if cloud's raindrop-generating pseudo-radioactivity Poisson process is assumed to continue operating to generate *new* random raindrop locations during the backward run, i.e. it always generates new independent randomness (it does *not* obey CPT invariance, or Lorentz or translation symmetries, except in a macroscopic statistical sense), then entropy would appear to continue increasing, that weird stuff (after a short temporary period – probably long enough for glass bottle fragments to surprisingly seem to be trying to reassemble, but not enough for them actually to succeed; and also not long enough to make balls bounce higher) would *not* be observed, and everybody, after recovering from the temporary shock of finding themselves driving their cars backwards, thereafter would think time was still continuing "forward" and also would not realize that any parity or charge reversal had occurred.

What if I just keep pushing an electron until it far-exceeds Planck momentum? Then what? I.e, some critic complains: "Suppose I build a huge accelerator to reach energies far exceeding your 'mode cutoff.' How is cloud going to stop me?" Essentially, whenever cloud-QFT is confronted with sampling data on raindrops corresponding to a wave with frequency greater than the mode-cutoff, then that data always can be *reinterpreted* as a linear combination of low-frequency waves *not* exceeding the bandlimit. See picture for (1+1)-dimensional example. This reinterpreted wave will *not* appear to be monochromatic with gigantic momentum. Rather, it will seem more like random omnidirected thermal noise with the same mean |square| as the original signal. In particular, if your huge accelerator consists of stationary components designed to keep applying "forward pushing" electric fields to electrons in the beam, then that electron, once it gets moving fast enough, will *stop interpreting* those fields as "unidirected forward pushing" but rather will think "I am in an omnidirected random noise field." Thenceforth, it will cease steady forward acceleration.



Singularities in Einstein General Relativity (GR) were a big problem, known to self-generate generically, and whenever they occur they invalidate, or anyhow manifestly demonstrate the incomplete nature of, that theory. R.Penrose hoped it could be proven ("cosmic censorship hypothesis," CCH) that any such singularities would always be hidden behind horizons and hence unobservable (unless you are willing to die to observe them), which would if correct be a partial salvage of GR. However, mathematical counterexamples to the CCH were found. Proponents then hoped certain weakened versions of the CCH might still be correct, albeit more and more ground keeps gradually being cut away from underneath their feet. That debate remains unresolved. In any case, if cloud governs graviton interactions too, then it cuts that gordian knot because it automatically induces mode cutoffs and imposes effective upper bounds on macroscopic mass-energy-densities and on the strengths of all fields, including gravity. This will effectively upper bound the absolute values of all GR curvature invariants. In that sense singularities can no longer exist.

What do I mean by **effective upper bounds**? Well, suppose you compress some mass, or energy, or a photon gas. You might think you can keep compressing to reach unboundedly great densities. And in fact, you can: that actually happened (in reverse) during the early universe "big bang." Similarly, you might imagine unboundedly strong fields (e.g. magnetic fields) could happen.

However, the problem with that is the cloud-universe *stops noticing* sufficiently high fields and high mass-energy densities. The only way anything else can notice them, is via some sort of interaction. For example, a field pulls on something, accelerating it. Or a high density emits gravitons, causing big gravity, so you can weigh something to notice it was dense. All those interactions must take place on raindrops. And they cannot because, due to cloud's "at most one Feynman vertex per raindrop" rule, we *run out of raindrops*. Once mass density or field strengths reach or exceed about 1 Planck unit, they "want" to interact much more than they can. And furthermore, since particles with super-Planckian energies are reinterpreted by cloud as a linear combination of lower-frequency modes, gravitons they do manage to emit, are not super-Planck-frequency gravitons, they are lower, sub-Planck, frequencies. So "weighing the huge density" fails to see a huge density. *Effectively*, in terms of what anything else in the cloud universe notices, mass-densities cannot exceed about 1 Planck unit.

Important implications about the early universe. In the standard FLRW cosmology model, the universe presently is Λ_{ein}-dominated, meaning the Einstein cosmical constant now is the biggest driver of the expansion of the universe. Somewhat earlier, the universe was "matter dominated," i.e. during that era, "matter" (stars, dust, gas) was the main driver. At a hotter earlier stage, it was "radiation dominated," i.e. the photon gas outweighed matter. I now point out that according to cloud, there must have been a still-earlier era, the "**super-Planck era**," dominated by radiation much hotter and denser than 1 in Planck temperature and density units – but behaving quite differently than sub-Planckian radiation because gravitons were "incapable of noticing" that super-Planck density and temperature, instead regarding it as merely order 1 density and temperature (in Planck units), regardless of how dense it really got.

Now the ("flat universe" subcase of the) Friedman equations tell us that during the matter-domination era, the universe's size parameter A(t) expanded with time t like $t^{2/3}$. During the radiation era, A(t) instead grew like $t^{1/2}$. Notice that both these expansion behaviors feature a magic "start time" t=0 with an infinite-density singularity.

But what about the present/future Λ_{ein}-dominated era, and what about the super-Planck era? Both answers actually are, mathematically, the same answer. Λ_{ein} acts like a magic kind of energy that retains the same density even after compression or expansion. Super-Plankian radiation effectively has the same property in cloud QFT. So therefore, general relativity predicts that in both these eras, the universe size parameter A(t) *expands exponentially*, causing "de Sitter spacetime" in both cases. The only difference is the numerical growth rate of that exponential expansion. In the future, the universe will double its linear size about every 6 billion years. But during the super-Planck era, the doubling time was more like 1 Planck time unit ($\approx 3\times 10^{60}$ times faster)!

And notice that, unlike the exponent 1/2 and 2/3 power laws, exponential growth does *not* feature any magic start time. The super-Planck era continues forever into the past and the Λ_{ein} era forever into the future. There never was any infinite density singularity. Also notice that cloud thus automatically generated exponential "**inflation**." Inflation was a concept invented by Alan H. Guth in 1980 and subsequently explored by many theorists and observers. There are good reasons to believe an inflationary era featuring vast exponential expansion of the universe, had to have happened during the early big bang. However, in order to drive inflation, those theorists had to hypothesize the existence of new fundamental particles ("inflatons") with just the right self-interaction properties; and had to suppose they all magically somehow initially got set up in the right state. No such particles have been discovered. Cloud QFT doesn't need no stinking inflatons. It just, very simply, more simply than any previous scheme, **logically forces** inflation to occur in any homogeneous isotropic universe, forever, during the super-Planck era.

Hawking's black-hole information-loss paradox: if you drop an encyclopedia into a black hole, where does that information go? Is it still present after the black hole "Hawking evaporates," i.e. could the encylopedia be back-deduced from post-evaporation state? If, on the other hand, that information is gone, then that invalidates the unitarity of quantum mechanics.

With cloud, there is no paradox. Cloud abolishes GR-singularities, and all time evolution is unitary *provided* all raindrop locations are exactly known – and anyone in possession of that knowledge could indeed (in principle) back-deduce the encylopedia from full knowledge of the the post-evaporation quantum state of the universe. However, with *unspecified* raindrop locations time-evolution converts "pure states" into "probability mixtures," which is *not* a unitary transformation, and then such back-deduction should be very impossible. Speaking as a New Yorker, I believe the situation can be summarized quite well in a single word: "Fuhgeddaboudit."

Cloud still enjoys **exact causality** via the same (rather remarkable and brilliant) mechanism via which it arose in old style QFT. The QFT propagators can allow propagation of (e.g.) an electron faster than light, with nonzero probability amplitude. This apparent "acausality" historically caused a lot of confusion. However, a particle moving from X to Y acausally, automatically will be accompanied by its antiparticle moving from Y to X (the two processes can be viewed as the same thing, and indeed in the view of appropriate Lorentz observers Y is temporally before X so that the latter interpretation is more natural) in such a way as to exactly cancel amplitudes, causing any experimental measurement at X necessarily to be unrelated to any experimental measurement at Y – that is, the operators for the two observables commute. This is proven by evaluating their commutator and proving it cancels to 0. Hence information cannot be transmitted faster than light and we live in a causal world. (Note this is a **reason antiparticles had to exist**; otherwise relativity and quantum physics would suffer a logical contradiction when you try to merge them.)

Wightman axioms: disobeyed and wrong. Cloud QED *disobeys* the "Wightman axioms" because the cloud disobeys microscopic Lorentz covariance, i.e. "axiom W0," i.e. there are two different Lorentz observers for whom cloud physics differ. (Indeed, W0 seems implicitly to assume the "arena" is Minkowski spacetime.) The Wightman axioms were central to the multi-decade many-researcher epically-unsuccessful struggle to rigorize QFT. I believe that one big reason for that failure was simply: that axiom-set is just physically incorrect.

Does Cloud give us quantum gravity & "theory of everything"? I will not answer this question right here and now. See the book. But I will make two remarks, one inspiring pessimism, the other optimism. First, the fact that introducing gravitons into (3+1)-dimensonal QFT causes *non*renormalizable *power law* infinities, kills Feller. Second, a notion that was clarified after t'Hooft & Veltman invented "dimensional regularization" is the "critical dimension" of a field theory. For the standard model, that dimension is 4, i.e. exactly the physical spacetime dimension, which is why the SM features "renormalizable infinities." If spacetime's dimensionality somehow could be "lowered to 3.99" then that would finitize those infinities, while raising it to 4.01 would destroy renormalizability. With gravitons, the critical dimension is 2. That (since 4>2) is why there are *non*renormalizable graviton infinities. But notice that we can make "bricks" have dimension 1 or 2, causing the cloud universe, when viewed microscopically, to *have* dimensionality below 4. Hence if the limiting process that shrinks $L_{brick}\to 0+$ shrinks the bricks "slowly enough," then one might hope that somehow that could rescue quantum gravity from its infinities.

Remarks on rigor in my (and other people's) physics (and/or the lack of it)

Here are six techniques to try to assure validity of a claim:

1. "Formally verified" (by a computer proof-checking system such as Isabelle or Mizar) math proofs.
2. Old-style human math proofs.
3. Data from physical experiments.
4. Data from computerized "math experiments."
5. Incomplete math proofs, e.g. involving "heuristic" or approximate reasoning, i.e. (what physicists often call) "models."
6. Resort to analogy.

Example. Nobody currently is able to settle the question "are there infinitely many twin prime pairs (p, p+2)?" but for each k≥2 it *has* been proven that there are infinitely many prime k-tuples $p_1<p_2<...<p_k$ with $p_k-p_1\le C_k$ for constants $C_2=246$, $C_3=398130$, and so on [each C_k is bounded by a computable finite bound; and the number of such ($\le C_k$)-wide prime k-tuples below X asymptotically is bounded between two positive constants times $(\ln X)^{-k}X$]. Also J-R.Chen proved an infinitude of primes p exist such that p+2 has at ≤2 prime factors. I regard those analogies as strong evidence the answer is "yes." [On the other hand, I suppose somebody could correctly note the theorem there is only one twin prime pair $n^2\pm1$, then cite that as evidence for "no"; and also note that there are no "twin squares" despite an infinitude of "squares" existing; but then I'd just think they were an idiot. Analogies, and assessing evidence generally, require judgment.]

And if we combine this analogy with heuristic reasoning by Hardy & Littlewood suggesting that the number of twin-prime pairs below X is asymptotic to $2CX(\ln X)^{-2}$ where C≈0.66016181584686957392781211 is a known constant; then observe that computer counts for many X up to 4×10^{18}, as well as counts within 10^{12}-long intervals centered at vastly larger X up to 10^{600}, all agree with H&L's estimates to within predicted statistical errors; and also observe that extremely large twin primes, e.g. $2996863034895\times2^{1290000}\pm1$, are known; then I feel extremely confident in "yes." Frankly, I feel more confident of that than of either "LHC discovered the Higgs boson" or Robertson & Seymour's graph minors theorem, despite the former being "observed by over 5000 experimentalist-authors" and the latter "mathematically proven," both in refereed journals. (And I suspect most physicists and mathematicians – and perhaps even Robertson, Seymour, or some of those 5000 – would share my feeling!) To be clear, I believe in both of those – and admire them as great discoveries – I just have *less* confidence in them than the unproven twin primes conjecture. However, if and when the graph minors theorem is re-proved with Mizar, *then* my confidence in it will rise above twin primes!

My book uses a mixture of techniques 2-6. Since human math proofs can contain errors, while certainly techniques 3-6 can err, it is best to provide K>1 different and independent arguments (preferably produced by different authors, too), because that will tend to reduce your chance of error to its *K*th power. E.g, to paraphrase Al Capone, "you can be more convincing with both a proof and computer experiments, than with either alone." Ideally everything would be done using techniques 1-3 only – and perhaps future authors will manage that – but I have given up on that as probably not feasible for me in my remaining lifespan.

Usually one can make crude quantitative estimates of how confident one feels, then use them to help plan future work. E.g. in the present case, if you believe in the summary's claims 1-8, plus the 6 juiciest claims in the section after, then you might say that a priori, theories of physics might have 50% chance of getting each of those 14 things right (independently), therefore Cloud lies within the top 2^{-14}=1/16384 fraction of physical theories in terms of how much you should believe in it. No proposal ever before has accomplished all those 14 despite 70 years of work by an entire community, plus Cloud seems a lot simpler than their best attempts. But: just one devastating unexpected objection still could kill Cloud. For Cloud's best claims – defeating UV infinities and series divergence – I'd advise you to read the book and consider its evidence, since neither is "proved"; rather, both are "supported by arguments and evidence." You'll need to decide for yourself how convincing those were and how close my "analogies" were; and what you think of them within the general milieu of all the book's other arguments re the whole cloud-QFT conception. Like judging a complex criminal case, there is a lot going on. For me personally, I'm feeling the case is strong, maybe over 90%; and I definitely like Cloud much better than any rival; but my opinions might change after others work on and/or attack it.

What I consider **unacceptable** – but unfortunately has been commonplace in theoretical physics during 1979-2023 – is *pretending* to have accomplished #2, while *hiding/disguising* gaps in the reasoning. The correct technique instead is to *highlight* those gaps, and *explicitly state* your assumptions, including unproved ones. That enables, rather than hinders, future progress. I believe that the contempt shown by most of the theoretical physics community for mathematical rigor is one of the biggest reasons for their almost total failure to make any notable fundamental progress during those 45 years. And if I here have outperformed them, I believe it is not because I came in with more talent or more knowledge; but rather mainly because of the different attitude I took. There are reasons mathematicians act the way they do. It is because their attitudes and safety techniques have been shown by long experience to be necessary for the reliability and health of the entire field. The remaining problems in fundamental physics are some of the hardest math problems around, and there is little to no sanity-restoration from experiment. So they *are* math. Treat them as such. Serious rigor problems are serious. A dismissive, contemptuous, and/or fraudulent attitude toward that is not going to get the job done.

The book

I hope you've enjoyed this brief, sketchy, and oversimplified tour and now are excited to learn more. If so, read the book. To whet appetites, I am circulating the present essay in April 2023, but as of that date the book still needs mucho cleaning and polishing. I hope it will be ready within a year.

Last time I checked, the book was 15-25 times the length of this essay, and had about 900 literature citations and 60 chapters. It grew out of my "computational complexity meets physics" research program, which stalled about 20 years ago when it hit physics too nonrigorous for computer science purposes. I wish I could say that I have converted quantum field theory into a rigorous part of mathematics. However, I failed. But I believe I have found the solution to all the big obstacles that were preventing that; done so by introducing new physical laws/concepts, and along the way exposed a lot of errors in prior work, plus discovered some surprises (the most astonishing being that de Sitter is crucial for QED series convergence); and made that convincing at levels short of mathematical rigor, but still pretty convincing. All the most prominent longstanding puzzles then have easy solutions. The overall picture is stunningly simple. And I think this effort can serve as a foundation for genuine rigorization attempts, and also for attempts to build "quantum gravity" and "theory of everything."
