

Universal Integrity Principle

PIU- Ψ

How the Pleno Operates

What is the cosmos? What is the Pleno? How does it operate?



diamond lattice $Fd3m$, $Z = 4$

an explanation to grasp the idea, with almost no mathematics

Manuel Alberto Celedón Mejía

Popular edition 5.6

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What is the cosmos? What is the Pleno? How does it operate?

A research program in fundamental physics
An explanation to grasp the idea, almost without mathematics

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The complete formal development —the corpus, the mathematical compendium and the verification notebooks that recompute every figure— is available for download at piuniversal.com and on Zenodo, under the same license.

The underlying question

Imagine someone told you that the gravity holding you in your chair, the light that lets you read this, the particles you are made of, and the great mysteries of the cosmos —dark matter, which holds the galaxies together though no one knows what it is made of, and dark energy, to which the acceleration of the universe’s expansion is attributed— are all the same thing, seen in different ways. Not separate forces, not different ingredients: a single substance, behaving in diverse forms.

Physics has carried an enormous problem for a century. Today we describe nature with two great theories that work wonderfully and that do not speak to each other. On one side, the theory of the very large: general relativity, which explains gravity, the stars, the galaxies and the shape of the entire universe. On the other, the theory of the very small: quantum mechanics, which describes particles, atoms and the subatomic world. Each reigns in its own domain; together, they contradict each other. When one tries to use the rules of the quantum world to describe gravity, the mathematics fills with meaningless infinities and everything collapses. Bridging that gap —they call it “quantum gravity,” and it is considered the greatest unsolved challenge in fundamental physics— has resisted the finest minds ever since. It is like having two perfect maps of the same city that, overlaid, do not fit.

Faced with that problem, almost every previous attempt accepts that there are two theories and looks for a way to *unite* them. PIU- Ψ inverts the question: **what if they were never two?** What if the large and the small are not two separate worlds to reconcile by force, but two faces of a *single* physical substance? In PIU- Ψ that substance is called the Pleno, and from it absolutely everything else springs.

- **It is physics, not philosophy.** PIU- Ψ is a **research program in fundamental physics** —the branch that seeks the ultimate laws of nature—: it starts from six precise principles, derives its results the way theorems are proven, and marks each statement with a label saying how far it has been proven.
- **It does not come to replace, but to explain.** What it does is *derive* relativity and quantum mechanics —it shows that both spring from a single root— and thereby **integrates them from a common base**. The laws science already has confirmed will keep working just the same; what the program adds is the root and the common trunk that hold them up.
- **It changes the question.** Instead of forcing two pieces to fit, it shows that they were always a single one. And from that single substance it takes on the questions current physics leaves open: what dark matter and dark energy are, why empty space holds far less energy than quantum theory predicts, what lies at the bottom of a black hole and at the beginning of the universe, why gravity is so weak, and why the quantum world behaves as it does.

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How this document is built

The running text tells the whole idea, in everyday images and almost without mathematics.

The **blue boxes** give the exact version of what the text has just told: the equation, the figure, the check the result is put to, and a label in the header saying how much is proven. Each one ends by saying what that result changes. The **red boxes** summarize and order what has already been explained.

The four **labels** say how far each claim has been proven: **[DERIVED]** complete proof; **[SLD]** strong logical deduction, structure proven and algebra still to be closed; **[CALIBRATED]** a value anchored to a measured datum, which is named; **[METHOD]** a matter of method, stating no result of its own. §18 develops them.

Every symbol is explained in words where it first appears. At the end of the book, after the twenty-four questions, there is also a glossary with the few that recur throughout the text. And the word **derive** has a strict sense here, which §2 defines and on which everything the program claims depends.

1. From a single equation, the laws that explain the dynamics of the universe

The starting point of PIU- Ψ is a question many of us have asked at some point —what if everything, gravity, light, matter, the cosmos, were at bottom the same?— carried to its ultimate consequences. If everything truly is a single substance, then from a precise mathematical description of that substance the known laws of physics must be deducible, step by step.

That is exactly what the program does. Its starting point is the first of its axioms —the principles accepted without proof, from which the rest is deduced—, **A1**. It says in a single sentence what the universe is in its entirety, and everything else rests on it:

The whole universe is ENERGY: unique, finite and conserved.

Energy: there are not two substances, nor one substance plus a stage to put it on; everything there is, is energy, and nothing else. **Unique**: there are no regions of the universe without it —the void as absence does not exist, because there is no outside—; everything that happens is the internal behavior of that energy, and that behavior can be represented with mathematics. **Finite**: nowhere does an infinite amount accumulate. And **conserved**: it is neither created nor destroyed, only transformed.

From those four words come the first three ingredients of the equation. The first: if the energy is unique and fills everything, asking how much there is per region is asking for a *density* —we write it ρ_P (pronounced “rho sub p”), and that small letter below is a reminder that its value falls in the realm of the tiniest sizes physics recognizes, the one that bears Planck’s name—, and that density is a property of the universe itself.

The second comes from putting “unique” together with “finite”. Unique means that there is no region without it; if at some point the medium could empty out completely, there would be a region with no energy there, and that is just what has been denied. Since the medium cannot empty out at any point, something must always be left over —and a remainder that cannot be crossed is a **floor**, a minimum value below which it does not go—. Finite means the symmetric thing on the other side: nowhere does an amount accumulate without limit, so there is also a **ceiling**. Two bounds, one below and one above. And the third ingredient comes from conservation.

If energy is only transformed, one has to say *into what*, and it can only be in two ways: **confined**, still and accumulated, which is what we call matter with mass; or **propagating**, traveling from one place to the next, which is what we call radiation. The heat of a body, the tension of a spring or the energy of a chemical bond are not separate forms: they are these same two, shared out among a great many tiny pieces. Every transformation is then a transit between the two, and conservation is written as a balance:

$$\Delta E_{\text{confined}} + \Delta E_{\text{propagating}} = 0$$

The triangle Δ reads “the change in”: how much that quantity has gone up or down. What leaves one branch enters the other, and the net sum is zero. Einstein’s famous $E = mc^2$ is then the particular case of that balance in which the conversion is total.

That balance ties together the changes of the two branches, but it does not reduce the two to one: how much energy is held at a point does not say at what rate that point is passing it to its neighbor. They are two distinct freedoms of the same place, and neither follows from the other. Describing the medium therefore calls for two numbers at each point, not one.

Two quantities like that —living at the same point with neither moving when the other moves— have a natural representation: the arrow. Draw one on a piece of paper and lengthen it without

turning it: the tip goes forward, following the arrow itself. Now turn it without lengthening it: the tip goes sideways, perpendicular to the arrow. The two movements come out at ninety degrees to each other, and that is why neither can be passed off as the other: stretching never turns, and turning never stretches. Hence the right angle is, in mathematics, the usual way of drawing two freedoms that do not get in each other's way.

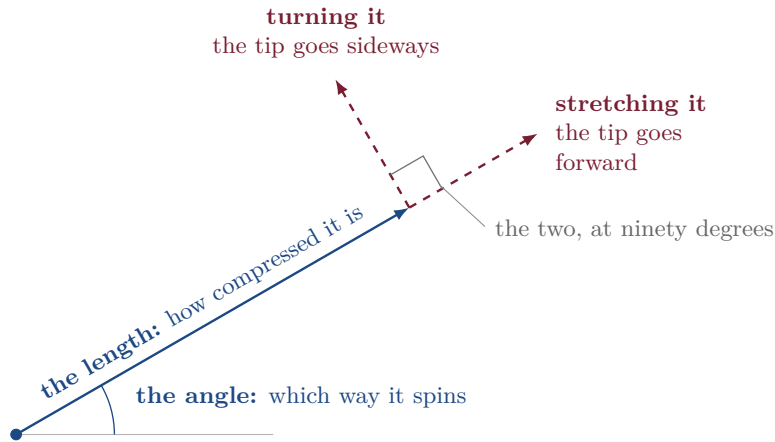


Figure 1: The two data of every point of the Pleno. The length of the arrow says how compressed the medium is there; its angle, which way it spins. Stretching it and turning it move the tip in directions that form a right angle, and that is why neither can be passed off as the other.

For two centuries mathematics has had —ever since Wessel, Argand and Gauss drew it on the plane— the number that is exactly that arrow: the *complex number*, which carries a size and an angle, and in which the imaginary unit i is the operation of turning a quarter turn—which is why multiplying twice by i gives -1 , half a turn—. When a magnitude has a value of its own at each point of space —like the temperature in every corner of a room—, physics says it is a *field*. Writing the Pleno as a field of complex numbers, one at each point, is the most economical way of saying “an energy with two branches that do not get in each other's way”: the length of the arrow says how compressed the medium is there, and its rotation carries the change. That step is not a proof: the program *postulates* that form of the field, and what the road from A1 supplies is the physical reason for it being that one and no other.

That object —a number with a size and an angle at each point— is precisely the one physics already uses to describe the smallest things. It is called the *wave function*, and since Schrödinger it has been written with the Greek letter Ψ (pronounced “psi”): it is the sign with which an electron, an atom, a molecule is described, and it sits at the very heart of the quantum formalism. What is observed of it is not the arrow but the square of its length, which gives the probability of finding the particle at each place. Here it is arrived at from the other end: starting from what the universe is.

That the road should end at the same letter —but applied to everything that exists, and not to one particle— is precisely what the program claims: that the quantum is not a hidden, separate corner of reality, but the texture of the single substance that forms it all. An electron is then a small, localized shape of that same field, and its wave function that piece seen close up. Hence the Ψ that accompanies its name. The field of the Pleno is written, then, like this:

$$\Psi = S \cdot e^{i\theta}$$

which is the compact writing of A1's two branches. The S is the length of the arrow, the branch of permanence: how compressed the medium is at that point. Its square is the energy density there: a wave twice as tall does not carry twice the energy but four times as much, and the same

happens here. The θ is its angle, the branch of change: which way it spins. Of that angle what counts is not its value but how it changes: turning every arrow by the same amount at once moves nothing, and what carries energy is the arrow turning with time or pointing differently from one point to the next. And $e^{i\theta}$ is the mathematical way of saying “turned through an angle θ ”: the arrow from before, with its length and its turn, written in a single letter. From those two quantities, and how they change from one point to the next, everything else springs.

That expression describes *what* the Pleno is. To know *how* it behaves, the theory adds its “fundamental equation,” known in PIU- Ψ simply as F1: a single compact recipe —what physicists call a *Lagrangian*: a system’s accounting book, where what it has of energy by moving is entered minus what it has stored— that fixes the dynamics of the medium completely, that is, how it moves and how it changes. It is built from a few starting principles —six precise statements about how the Pleno is, the Axioms of PIU- Ψ — and, once fixed, it is closed, immovable. From there, everything else follows by mathematical deduction, introducing no new ingredients along the way.

The formal development chains **seventy-four (74) derivations**. Thirty-nine (39) have the complete proof, with no gap; in another twenty-four (24) the chain is proven at its core, with one structural piece still to close or with one number taken from the world. From that same object come the laws of the physics books. **Twenty-seven (27)** are gathered in the list that follows, and they were chosen by a criterion: they are the recognized ones, those that carry the weight of physics and nearly all of which bear a proper name, from the two constants on which the rest stands to the instant when matter was formed. The program derives quite a few more; these are the ones that make it possible to check it against what was already measured and confirmed:

The two constants that hold up the edifice.

1. Newton’s gravitational constant, G , which sets how strongly two masses attract each other, with its value.
2. Planck’s quantum constant, $\hbar$ (pronounced “h-bar”), the one that sets the minimum step in which nature delivers energy —not in any amount whatever, but in separate portions—, also with its value.

Gravity and the shape of space.

3. Einstein’s field equations, the ones that say how matter curves space and time, entire: not only with their form, but with the number that goes in front.
4. The geometry of black holes, and an interior with no singularity —the point of infinite density where relativity stops working—: a finite density, the same for all of them, and a minimum mass below which none exists.
5. The very existence of a speed limit, and the Lorentz factor, which says how much time dilates and distances shorten as one approaches it.
6. That gravitational waves —tremors of space itself that propagate, like the ripples of a pond, when two enormous objects collide— travel at exactly the speed of light, as was measured to fourteen (14) figures of agreement in the merger of two neutron stars that in 2017 LIGO and Virgo saw in gravitational waves and the telescopes saw in light at the same time, GW170817.

The quantum world.

7. Schrödinger’s equation, the one that says how a particle’s wave changes with time, as an exact equivalence of the dynamics of the medium itself.

8. Heisenberg's uncertainty relation —the position of a particle and its momentum, which is its mass times its velocity, cannot both be pinned down at once without limit—, with its exact minimum.
9. The exact ceiling of quantum correlations —the Tsirelson bound—: how far measurements made on two separated particles can agree. If each one carried its answer written in advance they could not go past a certain point; nature overshoots it and stops dead a little beyond. The experiments that test Bell's inequality —from Clauser and Aspect to Zeilinger— have measured it for decades.
10. The Born rule: why the probability of finding a particle is the square of the length of its wave function.
11. The Dirac equation of the electron, with its spin —its own rotation— and its validity at speeds close to that of light, by two converging routes.

The forces and matter.

12. Maxwell's equations of electromagnetism for the free field —that of light traveling far from charges—, with the photon —the loose grain of light, the minimum portion in which light arrives— coming out massless and with its two polarizations, the two ways in which light vibrates sideways to its travel.
13. The structure of the Yang-Mills equations, those of the nuclear forces, and with it color confinement: why quarks —the three pieces a proton is made of— never appear alone. Color is the charge of the strong nuclear force, what electric charge is to electromagnetism.
14. Electric charge in whole units, and the exact neutrality of ordinary matter.
15. Pauli's exclusion principle —two electrons can never occupy the same place in the same state—, and with it the shell order of the electrons of an atom and the entire periodic table.
16. That protons and neutrons are made of three quarks, as Gell-Mann and Zweig established, and the size of the proton from a single input datum.

Heat.

17. Bose-Einstein statistics —the rule by which many particles of light share out the energy—, obtained by counting the medium's own *configurations*: each of the different ways the medium can settle.
18. The Stefan-Boltzmann law, with its exact coefficient —the coefficient is the number that multiplies in front of a formula, and it is the hardest part to get right—, and with it the glow of a hot body.
19. The Fermi-Dirac statistics of electrons, from the same count and with a single difference: photons pile up without limit in one and the same state, and electrons do not.

Stars.

20. The Chandrasekhar limit, the mass above which a spent star can no longer hold itself up and collapses, with its complete coefficient.

The cosmos.

21. The ratio between dark matter and ordinary matter, which turns out to be a pure number of geometry —pure means it comes out the same whether measured in meters or in inches, because it carries no units behind it—.

22. The four densities of the universe —how much dark energy, how much matter in all, and how much of it is dark and how much ordinary— in figures that fall next to those the Planck satellite measures: three inside its margin of error, and the fourth just over one.
23. The rate at which the universe expands, read as the hour its clock shows today.
24. The whole history of that expansion, checked against the measurements of DESI, the largest three-dimensional map of galaxies, with not a single fitted parameter —a parameter is a free number that can be retouched until the figures come out right, and here there is none—.
25. That dark energy does not thin out in the slightest as the universe expands.
26. The time-stretching of distant supernovae: their brightness rises and falls more slowly than that of nearby ones, in the exact proportion the expansion sets, and the data confirm it.

The beginning.

27. A beginning with no singularity: a universe that contracts, bounces off the upper wall of the medium before reaching its ceiling and, on the way back, forms the particles.

Each of those names —Newton, Einstein, Lorentz, Planck, Schrödinger, Heisenberg, Tsirelson, Bell, Born, Dirac, Maxwell, Yang, Mills, Pauli, Gell-Mann, Zweig, Bose, Stefan, Boltzmann, Fermi, Chandrasekhar— represents a lifetime of work, sometimes of whole generations, and each law was found separately, in different eras, to explain phenomena that seemed to have nothing in common: the gravity of the planets, the magnetism of a magnet, the behavior of an electron, the order of the periodic table, the death of a star, the glow of a hot body, the composition of the universe. Different chapters of physics, in different books. PIU- Ψ shows that all those chapters are, at bottom, the same story, that of the Pleno, written with the same pen and from the same first line: the common trunk from which grows a foliage we took to belong to separate trees.

And that changes what can be said of every one of those laws. All of them were known to be true —they are measured, some of them for centuries—, and many can be deduced from one another, but the chain always ends in something accepted because it is measured: physics knew *that* they held and, on reaching the bottom, not *why*. That gravity should be as weak as it is, that electric charge should come in exact units, that correlations between separated particles should stop precisely where they stop: accepted facts, measured to enormous precision, and with no explanation below them. In PIU- Ψ those facts remain the same facts and remain measured the same; what changes is that they stop being the bottom of the chain, because each one comes to have beneath it the reason why it comes out with the value it has and not another.

The starting point: the six axioms and F1

[DERIVED]

Six axioms fix what the medium is, and the minimal Lagrangian that respects all of them is a single equation: F1.

A1: a single, finite, conserved energy, with no vacuum. **A2:** a lower wall preventing the medium from vanishing. **A3:** a single cost of change for every mode of the medium —a mode is each of the independent ways the medium has of vibrating or deforming, like each note a string can give—, with a single ratio between what changes with time and what changes from one point to the next, so that the laws of the Pleno are the same for any observer. **A4:** a grain of size ℓ_P , below which there is no finer structure. **A5:** the phase —the angle of the arrow, which way the hand points— does not appear in the potential, the energy the medium stores by its shape; only the modulus —the length of the arrow, that S — costs energy. Hence turning the phase as a whole, everywhere and at once, changes nothing of what happens. **A6:** upper saturation; the medium cannot be compressed without end.

A3 does not postulate relativity, nor the speed of light. It postulates one thing only: that the medium

measure change in time and change from one point to the next with a single yardstick. From that follow, already as theorems, the rules by which one observer's measurements are translated into those of another in motion —what physicists call the Lorentz group—, the existence of a maximum speed, and the laws looking the same from any state of motion. What is placed in the premises is the uniqueness of the cost of change; relativity is harvested.

Reading A1 region by region gives the density of the medium, ρ_P . And writing conservation as a balance between two orthogonal branches —the right angle of the arrow: what the medium retains as structure and what it propagates as change— *motivates* the form of the field, $\Psi = S e^{i\theta}$. The complex field is the minimal expression of that balance: A2 guarantees that S is always positive, and A5, that the phase turns freely. The form is postulated, and the road from A1 gives the physical reason for it being that one: it motivates the form, it does not derive it.

With that field, the minimal Lagrangian that respects the six axioms —four terms, each one answering what an axiom requires— is F1:

$$\mathcal{L}_{F1} = \frac{1}{2} \rho_P c^2 \ell_P^2 \partial_\mu \Psi^* \partial^\mu \Psi - V(S) - \frac{\rho_P c^2 \ell_P^4}{40} (\square S)^2 - V_q^{\text{dens}}(S)$$

The symbol ∂ says “how much this changes on advancing a little,” and the subscript μ runs over the four directions in which one can advance: the three of space and that of time. Read with that in hand, the formula has four pieces. The **kinetic** term —the first, the one with the ∂ 's— is that of the change of the field from one point to another and from one instant to the next: it is the one that makes the field propagate, and it carries the density of the medium and its grain in its coefficient. And it splits exactly into A1's two branches, one for S and another for θ , for the same reason an arrow was needed: lengthening it and turning it are two movements at ninety degrees to each other, and what goes at a right angle adds up separately. One piece of the cost is put up by the stretching and another by the turning, with nothing shared between the two. The asterisk in Ψ^* marks the same arrow with its angle reversed, and multiplying one by the other erases the angle and leaves the length. The **potential** $V(S)$, the energy each value of the modulus costs, holds the stable configurations. The **flexural** term, named for *flexure* or bending, penalizes curvature of the modulus: $\square S$ compares the value of the modulus at a point with the average of its immediate surroundings, and is zero when the two coincide: when the modulus does not curve there. The $1/40$ that accompanies it is not chosen: it comes from averaging, over all the directions in which the diamond lattice can ripple, how much the pattern curves from one node to its neighbors. It is a number of the lattice. And the **Klauder** term, V_q^{dens} , grows as S approaches zero, a value no configuration reaches; it bears the name of John R. Klauder, the physicist who developed the way to treat in quantum theory a magnitude that can only be positive —affine quantization—.

Stretching a sheet and bending it are two different ways of deforming it, and a thin sheet resists the first far more than the second: a sheet of steel bends by hand, but there is no stretching it. Bending it only starts to cost in earnest when the curve becomes as tight as the thickness of the sheet. The flexural term is the Pleno's resistance *to being bent*, and in it the grain plays the role of the thickness: a ripple much wider than ℓ_P barely feels it, and one the size of the grain costs dearly. The material objects to anything finer than itself occurring. That grain measures some 10^{-35} meters: twenty (20) orders of magnitude below a proton —that is, with twenty zeros in between—. At any scale an instrument can reach, the medium behaves as though it were smooth.

None of the four can be removed without the medium losing something it needs: to propagate, to rest, to have a grain, not to vanish. F1 is written with **three primary quantities**: the density ρ_P , the maximum rate of change c , and the grain ℓ_P . Everything else appearing in the program — G , $\hbar$, the scale of the potential, the two walls— follows from those three and from the geometry of the lattice. The form of each wall has an author: the lower one is Klauder's; the upper one, the one Alan N. Gent wrote in 1996 for a rubber that will stretch no further. And the geometry of the lattice is fixed by the minimum of F1: if the medium has a grain of fixed size, repeating it to fill space allows only a few arrangements, and the medium adopts the one that costs least energy, just as a metal does on solidifying. That arrangement is what is here called the crystal, and from its shape come pure numbers such as the $1/40$ of the flexural term.

What this changes. Physics today works with several fundamental objects, each with its own constants, and when a sector does not match, a term is added to it. Here there is a single object and

nothing can be added to it: gravity, the quantum and the cosmos are not extensions of F1, they are *evaluations* of F1. Every result arrives with these same coefficients or it does not arrive.

2. Deriving is not fitting

There are two ways to arrive at a formula in physics, and the distance between them is the distance between describing and explaining. The first is to **fit**: take a measurement, propose a formula with a few knobs, and turn the knobs until the formula passes through the data. It is legitimate and has built much of our knowledge, but it has a known limit: a formula with enough knobs always ends up succeeding, so success by itself proves little. The second is to **derive**: start from a fixed point and advance by mathematical and algebraic steps in which each one follows from the previous without introducing anything new along the way, just as a theorem is proved. Here there is nothing to turn, nothing that can be adjusted, and so the result can come out wrong. That it comes out right does prove something.

And how does one derive anything from F1? A Lagrangian is a precise way of keeping a system's accounts: at each instant it takes the energy the system has by moving —the kinetic— and subtracts from it the energy stored by its position and its shape —the potential—. That subtraction does not measure how much energy there is, which does not change; it measures how that energy is split between the two forms along each stretch of the path.

Summed over a complete history, the subtraction gives a single number, called the *action*. And of all the histories the system could follow, the one it actually follows is the one whose number does not change if the history is imagined slightly different: pushed aside along some stretch and brought back to the same point of arrival. What is compared are histories, not equations: nothing in the physics is altered, one only asks what would have happened to the number had the world taken a neighboring path. It is the same feature that marks the bottom of a valley: the only point where taking a step to one side or the other leaves the altitude unchanged, while on the slope any step changes it. Textbooks call it the principle of stationary action, or of least action —Maupertuis stated it and Hamilton gave it its general form; for light, Fermat had seen it earlier—, and it is one of the firmest pieces of physics: the curve a stone traces when thrown into the air, the orbit of a planet and the path of a ray of light entering water all follow from it.

From there on there is no choice. An eighteenth-century procedure, that of Euler and Lagrange, takes the Lagrangian and returns the equations of motion: how the system evolves, what stable shapes it admits and what quantities are conserved in it. It is the same procedure all of theoretical physics uses, and it leaves no room for creativity: applied to the same Lagrangian, two people always obtain the same equation.

From that general equation to a known law there is one more step: looking at it in a particular **regime**. The same equation behaves differently depending on whether it is observed at low speeds or close to the speed of light, at enormous distances or at the size of the grain, with configurations disordered or all aligned. Restricting the view to a regime simplifies the equation, and what remains in $\text{PIU-}\Psi$ is, case after case, a formula physics already had. That is an *effective limit*, and it is the mechanism by which a deeper theory contains its predecessors instead of repealing them: Newton's mechanics did not cease to be true when Einstein arrived; it remained as the limit of relativity for low speeds and weak fields.

Each time a regime is chosen and the computation is done, the theory has no margin: it returns the number it returns. If F1 gave a gravity too strong, or a radiation with the wrong coefficient, or a proportion of dark matter that did not match, there would be nothing to retouch —F1 is the same object in every case, and a knob that fixed one result would wreck the others—.

The three primary quantities are not knobs either: they are the yardstick everything is measured

with. They are the density of the medium, ρ_P , how much substance there is in each piece of it; the size of its grain, ℓ_P , below which there is no finer structure; and the speed c , the only rate at which the medium transmits any change. Those three, and nothing more, translate the program's computations into meters, kilos and seconds. Their value says what our meter is like, not what the Pleno is like, and not one of the numbers the program derives depends on it.

That laws obtained in unrelated regimes —gravity and electric charge, the glow of a hot body and the composition of the cosmos— all come out of the same object with nothing adjusted is, exactly, what a fit cannot imitate. A fit reproduces; it does not explain. Fitting a curve to some data delivers a number that agrees, and nothing else: if tomorrow the measurement is sharpened, it is fitted again. A derivation delivers the number and, with it, the reason it is that one, so that it cannot be moved without taking apart what lies beneath it. And that is why a fit that hits one sector says nothing about the next, whereas here the same object has to hit all eight at once.

The Euler-Lagrange procedure and the effective limit

[DERIVED]

A standard machinery turns a Lagrangian into equations of motion, and looking at them in a particular regime returns the known laws.

The step from a Lagrangian to the equations of the system is taken by the Euler-Lagrange equation, which for a field Ψ reads

$$\partial_\mu \left(\frac{\partial \mathcal{L}}{\partial (\partial_\mu \Psi)} \right) - \frac{\partial \mathcal{L}}{\partial \Psi} = 0.$$

The symbol ∂ is the derivative, the operation that measures how much something changes on advancing a little, and the index μ runs over time and the three directions of space. The first term gathers how much the Lagrangian depends on how fast the field changes from one point to the next, and how that dependence varies across space and time; the second, how much it depends on the value of the field itself. Requiring their difference to be zero selects, among all imaginable histories of the system, the one whose action does not change when the history is slightly retouched. When the Lagrangian also contains the curvature of the field, like the flexural term of F1, the equation gains a third term of the same kind. It is a closed procedure: given the Lagrangian, the equation is fixed.

That tool already returns known physics. Applied to the Lagrangian of a classical particle it reproduces Newton's laws; to that of the electromagnetic field, Maxwell's equations; and to the Einstein-Hilbert action, the field equations of general relativity. Applied to F1, it returns the dynamical equation of the Pleno —one for the modulus, another for the phase— and the conserved current accompanying the phase symmetry, by Noether's theorem, which associates with every symmetry a quantity that is conserved. The phase symmetry is that of turning all the hands of the medium at once, everywhere and by the same angle: once that is done, the Pleno is left as it was. And current is the name that quantity takes when it can be neither created nor destroyed at any point, but only pass from one place to the next.

An **effective limit** is what remains of that equation when it is restricted to a regime. Formally it is an expansion in a small parameter —the equation written as a sum of ever smaller terms, in which the first tells almost everything—: the small number is the speed compared with that of light (v/c) when one goes slowly, or the size of the grain compared with the wavelength —the distance between two successive crests— when the wave is much longer than the grain. A third route uses no small number at all: averaging over configurations, when the object is collective behavior. It is a giving up of detail: the state of each cell is replaced by that of the crowd and one asks what the crowd does, just as one speaks of the temperature or the pressure of a gas instead of following its molecules one by one. Higher-order terms are dropped and a simpler equation appears, with its domain of validity explicit.

What this changes. The laws physics discovered one by one —Newton, Maxwell, Einstein— are each obtained today from their own starting point, and there is no bridge leading from one to another. The grave case is gravity and quantum mechanics: each rests on a starting point of its own, and reconciling them is the oldest open problem in physics. With this machinery, the three come out of the same procedure applied to different Lagrangians; and applied to F1, out of the same object come Einstein's field equations and Schrödinger's equation, with no negotiation between them, and with them the rest. That is the result the program puts ahead of all the others. That is why the results

of the program form a tree and not a list: each rests on the ones beneath it, and cutting off a branch leaves everything that grows from it unsupported.

Three different things said with the same word

[METHOD]

Reproducing, deriving and explaining are three different operations, and a derived result claims only the second.

Reproducing is obtaining a known result inside the formalism, with the target already nailed down by established physics: the Schwarzschild solution —the geometry of space around a star or a black hole— follows from Einstein’s equations without matter — $R_{\mu\nu} = 0$, which is how one writes “in this region there is nothing curving space”— plus the requirement that everything be the same in every direction, and it follows the same way in any relativity textbook. **Deriving** is obtaining it from F1 and the axioms, with the algebra in view and no imported premise that brings the result already in it. The 8/9 coefficient that fixes the energy of the electromagnetic field, for instance, comes from summing circulations over the faces of the lattice —going around the border of each face of the crystal the medium organizes into and noting how much the phase has turned on coming back to the starting point—, and that sum returns whatever number it returns, with nowhere to adjust it. **Explaining** is saying, in addition, *why* nature has that structure and not another.

The **[DERIVED]** label asserts exactly the second. What is claimed is not that a number agrees: it is that the whole chain leading to it starts at F1 and imports nothing along the way. And a reproduction is not promoted to a derivation by the number coming out right; the criterion is the direction of the arrow, whether known physics comes out as a limit or goes in as a premise. The third the label does not claim: why the medium has the grain and the density it has lies outside what **[DERIVED]** asserts.

What this changes. Knowing the target in advance helps a theory with knobs, because it tells it which way to turn them. With no free coefficients there is nothing to aim with: the equation returns the number it returns, and that this forced number should also match the measured one is exactly what has to be explained.

The whole building has the shape of a tree, and like a tree it holds itself up: from below. In the ground, the **root** —the six axioms and the three primary quantities—; on it, the **trunk**, which is F1, the single dynamical object; out of it come the two first **branches** F1 itself fixes (the lattice the medium crystallizes into and the energy well it rests in); and above, the **foliage**: the eight sectors where the program ends up comparing itself with the world.

And no arrow comes in from the sides: everything that rises through that tree comes in through the root, except the positional reading, which is taken from the world, enters through the cosmos leaf and says at what point along its path the medium stands today. That path is the change the medium has accumulated, and it is what we see as the history of the universe. The reading says at what point of that path we are: the hour, not the workings of the clock.

That distinction is what the word **calibrated** carries every time it appears in the header of a box: the form of the result belongs to the program, and today’s value is read off the world. It does not mean there is a screw to turn until the number comes out right. And from it follows a practical difference before every figure in the book: in a theory with knobs, getting it right is what one expects, because that is what the knobs are for; here, every figure that comes out right could have come out wrong.

3. A single substance that is everything

Imagine that the universe is not made of loose things floating in a void, but is a single continuous material that fills absolutely everything, without gaps. What we call “empty space” would not be empty: it would be that material at rest.

A good image is that of an elastic medium: a gelatin filling everything, or a block of glass extending in all directions. And everything that exists is a shape that medium takes. Just as

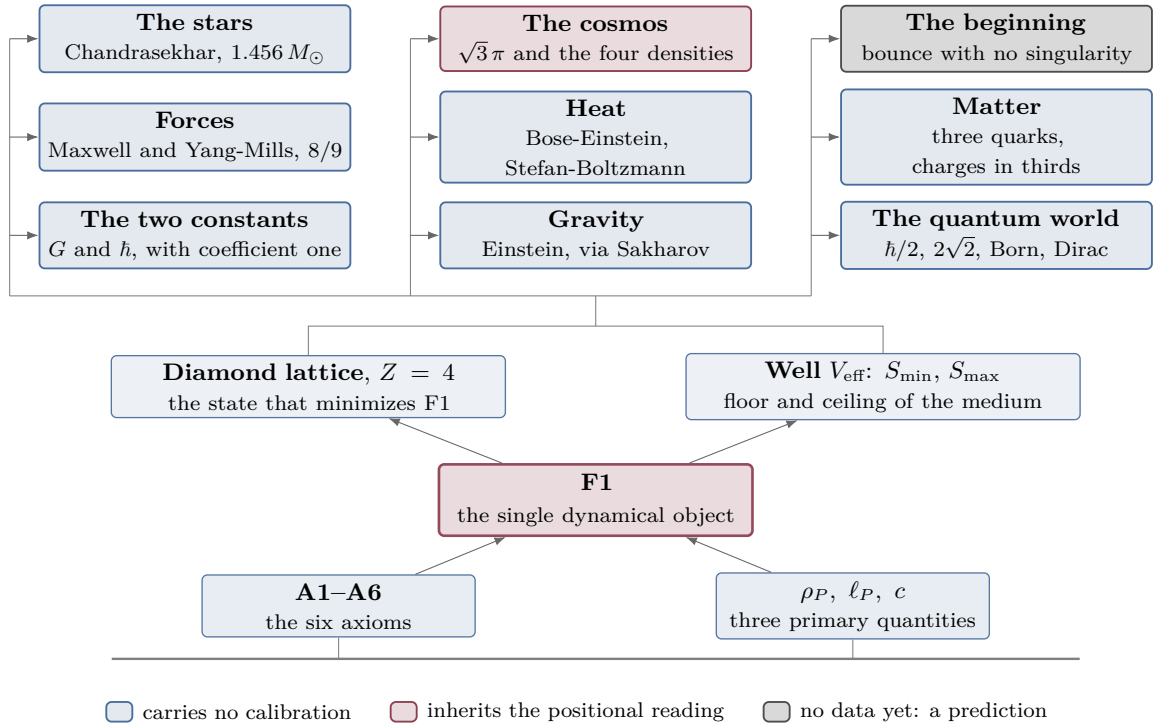


Figure 2: The tree of the program. The lattice and the well are the two first branches F1 itself fixes. Above, out of the same trunk, grow the eight sectors where the result is checked against the world; forces and matter, which form a single sector, take two leaves. The color distinguishes three kinds of leaves: those that carry no calibration; the cosmos leaf, which inherits the *positional reading*, the one that says at what point along its path the medium stands today; and the beginning leaf, which has no data yet to be compared with and is a prediction.

the waves, the foam and the currents of the sea are not things distinct from water but shapes of water, particles, light and gravity are not things distinct from the Pleno but shapes of the Pleno. A compression here, a spin there, a wave running through it. That is the central wager of PIU- Ψ , and everything else rests on it: a single substance, and the entire universe as its countless ways of moving.

The wager does not say the universe is *filled* with a substance: it says the universe *is* that substance, and that there is nothing else. A stage to put it on would be something else. A void between its parts would be something else. A law separate from it would be something else. PIU- Ψ has none of the three, and that absence is what forces everything else to be derived instead of assumed.

The first consequence is that **the void drops out of the inventory of the universe**. What physics calls the vacuum is, here, the medium in its state of rest: the lowest-energy configuration the Pleno admits. And in it the medium is still there, with a density that is not zero and cannot be, because the cost of annulling it grows without limit as it approaches zero, and the medium never gets there. The absence of vacuum is an impossibility of the material.

That changes the nature of one of the most serious problems in physics: the largest known mismatch between a prediction and a measurement.

Quantum theory assigns energy to empty space. It computes it by adding up the minimal tremor its fields keep even when nothing is happening —what physicists call the zero-point energy, the remainder of stirring there is no way to remove—. That energy has a consequence that can be measured: it pushes the universe to expand ever faster, and the observed rate says how much of it there actually is. There turns out to be very little indeed. The sum of the tremors exceeds what is observed by a factor of 10^{123} : a one followed by a hundred and twenty-three zeros.

In the Pleno that sum is not carried out, and not out of neglect: there is nowhere to carry it out. Adding up tremors of the vacuum presupposes that there is a vacuum to add them over, and here there is none; what there is is a medium, and its rest energy is not a sum of tremors but the balance between its two walls —the one that keeps it from vanishing and the one that keeps it from compressing without end—. It is energy of structure, what it costs to be the medium it is.

And with that the problem changes shape, on two sides at once. The first: that state of rest —the bottom between the two walls, the level the medium does not go below— **is the zero of the scale, not an excess over it**. What weighs in the gravity of the universe is not that bottom, but how far the medium departs from it, and those are two distinct quantities that the physics of the vacuum had been adding as if they were one.

The second: the number itself comes apart. That 10^{123} turns out to be, up to a factor of proportion coming out of the geometry, the age of the universe counted in Planck ticks —a tick is the time light takes to cross one grain of the medium— and squared. Any universe that has run that many ticks has that number by pure arithmetic. There is no need to explain why a density is tuned to a hundred and twenty-three (123) digits; what needs explaining is how many ticks the clock has been running, and that is an age, not a coincidence.

The medium at rest has, then, a density of its own, and it is enormous. What the expansion reveals is not that density, but how far the medium departs today from its rest, which is tiny. It is the difference between weighing the ocean and measuring the height of the tide.

The second is that **the distinction between contents and container disappears**. In ordinary physics there is a spacetime and there are things inside it, and the relation between the two is the central problem of the last century. In the Pleno there are not two categories to relate: what we call space is the extension of the medium itself, and what we call particles are shapes that medium takes. Sea ice is not *in* the water the way a stone is in a box: the ice *is* water, in

another configuration. It has its own outline, it holds together, it can be turned over —and it is still not another substance—. Asking what lies between the ice and the water is asking wrongly.

The third is the one that gives the program its name. If there is a single substance, then all the laws of physics are statements about the same object, and they have to be compatible with one another by construction, not by luck or by negotiation. Gravity and quantum mechanics cannot contradict each other for the same reason two descriptions of the same horse cannot: if they do, one of them is wrong. That is the *integrity* in the name *Universal Integrity Principle*: unity as a constraint the program imposes on itself and cannot afterwards escape.

And the fourth is that a single substance means **a single set of properties**. The Pleno has a density, a minimum grain and a maximum rate of change, and it has nothing else. Every time the program wants to explain a new phenomenon —electric charge, the glow of a star, the proportion of dark matter— it has to do so with those three quantities and with the geometry the medium organizes itself into. That is why every result that comes out counts: there is nowhere to adjust it from.

And no, this is not the ether

At the end of the nineteenth century physics had a medium that filled space and through which light traveled: the ether. It was looked for carefully, it did not turn up, and the idea fell, rightly. Anyone arriving here with that history in mind does well to be suspicious, and the comparison, point by point, clears it up. They resemble each other in one respect only: both speak of a medium. Past that they share nothing, and the differences are not matters of nuance.

The ether sat inside space; the Pleno *is* space. The ether was a material occupying a stage that already existed, the way water occupies a swimming pool. Here there is no pool. What we call space is the extension of the medium itself, and removing the Pleno would not leave an empty space: it would leave nothing, not even the place.

The ether had an absolute rest; in the Pleno there is nothing to be still with respect to. That was its death sentence. If there is a medium inside space, moving with respect to it has to show: the Earth ought to feel a kind of wind, and light ought to take longer one way than the other. Albert Michelson and Edward Morley measured that difference in 1887 with precision to spare and found zero. In the Pleno the question does not even arise, because there is no second object against which to measure a displacement. What the program measures is how much the medium is compressed and how much its phase turns, and those two come out the same for any observer, however he moves.

In the ether matter passed through it; in the Pleno matter *is* the medium. The ether forced one to ask whether the Earth dragged it along, cut cleanly through it, or pushed it ahead, and no answer fitted all the measurements at once. Here nothing passes through anything. A planet is not an object making its way through the medium: it is a configuration of the medium that travels, the way the ruck in a carpet crosses the room from one end to the other without the carpet moving from its place.

The ether demanded an impossible material; the Pleno demands none. To carry light—a transverse wave, and a very fast one—the ether had to be stiffer than steel. Not to slow the planets down, it had to be subtler than air. Nobody managed to imagine a material that was both, and the problem was real, not an oversight of its defenders. Here there are no bodies moving about inside that would have to be slowed, so the stiffness of the medium has nothing to fight with: it fixes the speed at which any change propagates, and that is all that is asked of it.

The ether contradicted relativity; the Pleno delivers it. To save the ether after that experiment, one had to add that bodies shrink as they move —George FitzGerald and Hendrik

Lorentz proposed it—, a rule put in by hand to plug the hole. Einstein dispensed with the medium and obtained that shrinking as a consequence. Here the factor by which inertia and energy grow on approaching the speed of light comes out of F1 itself the moment one writes a deformation that travels, and from the same computation relativistic momentum and energy are read off. Relativity is not contradicted, nor grudgingly tolerated: it comes out of the medium.

The ether explained nothing else; the Pleno has to explain everything. The ether was a support for light, and only that. It did not give gravity, nor electric charge, nor the spin of the electron, nor the proportion of dark matter. It was added to physics and returned nothing in exchange: an assumption that cost and did not pay. The Pleno does the opposite: out of it come the constant of gravitation, Planck's constant, Maxwell's equations, Einstein's, the structure of Dirac's and the split of the dark sector.

The ether was patched; here there is nothing to patch. Every new experiment forced another property onto it —partial dragging, shrinking, selective stiffness— and each addition saved it from that measurement and from no other. A medium with enough additions survives anything, and that is why it ended up saying nothing. The Pleno admits no such treatment: it is a single object for all eight sectors at once, and a patch that fixed one would wreck the rest.

And the ether fell by the right method, which is the one applied here. It predicted something observable, it was looked for, and it was not there. That is exactly what one must be able to do to a theory. The Pleno predicts the null result of that experiment —not as a way out, but as a consequence of having no privileged rest— and puts predictions of its own on the table, each with its number.

4. How it is organized: a diamond-shaped crystal

Here is the first thing that sounds like a contradiction. The Pleno is a continuous material, with no gaps and no separate pieces; and at the same time it has an internal structure that repeats and a minimum size below which there is nothing finer. Which is it?

Both, because they do not get in each other's way. The minimum size of the Pleno is not the size of a piece: it is the tightest fold the medium will take. Fold a cloth. A wide fold takes no effort; a tighter one already costs; and below a certain fineness the cloth simply refuses. Not because it is made of bricks —it is continuous, and it has no gaps— but because folding it costs more the tighter the fold. There is, then, a fold that cannot be made in it, and that limit is a property of the cloth, not a piece inside it.

The Pleno behaves this way, and it is written into its equation: F1 carries a term that charges for curvature, and charges for it as the fourth power of how fine the ripple is. At large sizes that cost goes unnoticed. On approaching the grain it shoots up, and the medium stops admitting finer variations. That size —that of the tightest possible fold— is the grain of the Pleno, ℓ_P . It is one of the six starting principles of the program, and it is there for two reasons: because every known physical medium has a scale below which it stops behaving as a continuum, and because a medium without that limit would admit ripples as fine as one liked, which is where a good part of the infinities that have plagued the physics of the last century come from.

With the grain in place, the crystal stops being a surprise. The Pleno structures itself internally in a regular, repeated pattern, just like the atoms in a gemstone, and with one difference: between the atoms of a gem there are gaps, and in the Pleno there are none. What repeats is not pieces set side by side, but the way the medium itself folds, repeated seamlessly and with nothing in between.

And not just any pattern, but the same one a diamond has. In a diamond, each carbon atom bonds to four others, and those four are not placed just anywhere: they surround the atom,

which sits at the center, pointing at the four vertices of a regular tetrahedron —a pyramid with four equal faces, all equilateral triangles—, which leaves them as far apart from one another as possible. It is the only way to distribute four bonds in space without favoring any direction, and the network they form, locked together in all three directions, makes diamond the hardest natural material there is.

The Pleno shares that architecture: each of its cells bonds to four others in that same tetrahedral arrangement. A cell is not a piece of substance set apart from the others, but a stretch of the pattern: the way each fold of that cloth is a fold without ceasing to be cloth. Bonding to four others means that the pattern of one cell continues into that of its neighbors along four directions, and that it is those four at any point of the medium and in whatever orientation one looks at it. That uniformity is what later makes it possible to average over the lattice and get fixed numbers, instead of numbers that depend on where one looks. From that simple geometry —“four neighbors in a tetrahedron”— come a great many of the program’s numbers.

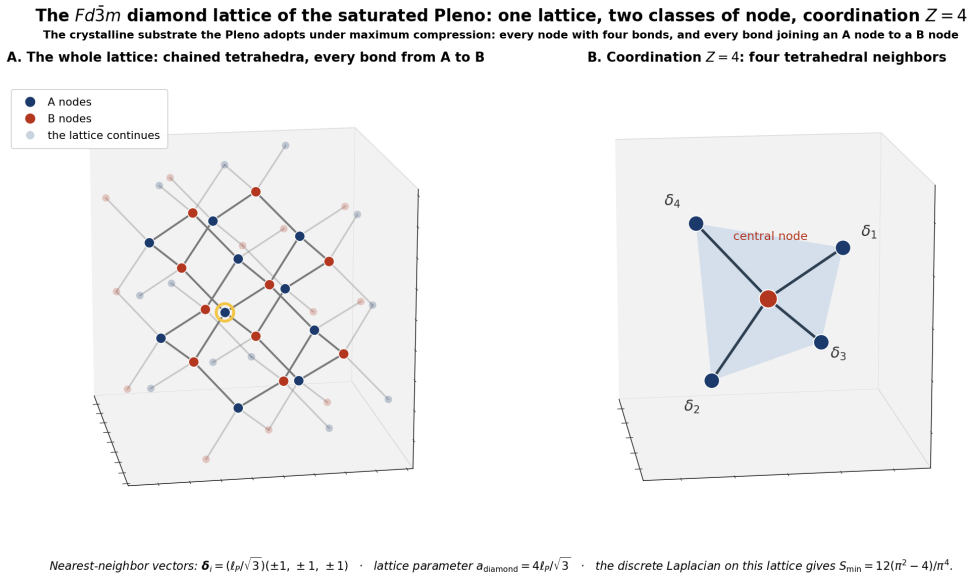


Figure 3: The internal structure of the Pleno. **Left**, the whole lattice: a single lattice whose nodes —the cells of the medium— fall into two classes, A and B, in such a way that every bond joins a node of one class to a node of the other; the pale nodes at the edge are the lattice continuing, because in the Pleno there are no edges and every node has its four bonds. **Right**, a single node with its four neighbors, which point at the vertices of a tetrahedron —the same architecture as diamond—. From this geometry come the two pure numbers of the medium: its floor and its ceiling.

The diamond structure is not postulated, it is *derived*. The Pleno has no privileged direction, and that rules out almost every way of bonding a cell to its neighbors. With three bonds the pattern is tied down within a plane and loose along the perpendicular direction, so that direction would end up privileged by default. With four, pointing at the vertices of a tetrahedron, it is locked in all three directions of space, and four is the smallest number for which that happens. And among the ways of stacking four-neighbor cells, diamond’s is the one in which bending costs the medium the least energy. It is the same principle by which carbon, squeezed equally in every direction, forms diamond. From that single geometric form follows, chained and with proof, much of what the theory produces: the floor and the ceiling of the medium, the $8/9$ coefficient of electromagnetism, the proportion $\sqrt{3}\pi$ between dark and ordinary matter. The geometry of the crystal is, at the same time, a derived consequence and the branch out of which almost everything else grows.

The floor and the ceiling of the medium are not fixed by the form of the equation: they are fixed by the form of the crystal.

F1's potential has the shape of a well, but the form of the Lagrangian does not by itself say at which value of the modulus its bottom falls —the floor, where the medium rests— nor where its upper wall rises, the ceiling. That is fixed by the microstructure the medium adopts, and F1 says which one it is: the diamond lattice. Four neighbors per cell is the minimum that privileges no direction —the simplest case of the bound that Philippe Delsarte, Jean-Marie Goethals and Johan Seidel gave in 1977 for spreading directions over a sphere, obtained here from A1—, and it is also the coordination that costs the medium the least energy. And among the possible stackings the decision is made by the flexural term: it charges each undulation at the fourth power of its fineness —the fineness multiplied four times by itself, which runs away far faster—, while the kinetic term charges it only at the square, so it comes out cheaper for the medium to concentrate its whole pattern into a single wavelength than to spread it over several. Only the diamond stacking manages this; its hexagonal rivals —the same tetrahedron, with the layers alternating instead of repeating— need at least two.

The **floor** comes from how the lattice undulates, and what the ratio measures is this: *what fraction of the cost of a smooth medium survives in a medium with grain*. In a continuous medium, an undulation costs more the finer it is, in exact proportion to the square of its fineness; in the lattice, the grain makes the finest ones cheaper. No undulation can be finer than two cells, because there is nothing between one cell and the next to draw it; on reaching that size it stops getting finer however hard it is squeezed, and its cost stops growing. A continuous medium, with nothing to cap it, would go on making them costlier without end. Take the real cost of all the undulations the lattice admits —the one given by the discrete Laplacian, the operation that compares the value of the field at each node with that of its neighbors—, average it, and divide by the average the same medium would have if it were continuous —the smooth curve obtained when nothing caps the fineness, its parabolic approximation—:

$$S_{\min} = \frac{\langle D_{\text{lat}} \rangle}{\langle D_{\text{lat}}^{\text{par}} \rangle} = \frac{12(\pi^2 - 4)}{\pi^4} = 0.7230871.$$

The angle brackets $\langle \rangle$ are the usual notation for “average of,” above the lattice's and below the continuous medium's. The result, 0.7231, says that in a medium with grain a little less than three quarters of the cost a smooth one would have survives: the rest the lattice saves by not being able to draw undulations finer than its cells. And it is geometry of the crystal, with no dynamics involved: neither the potential nor any measurement enters.

F1's well has its minimum at exactly that value, but **that is not the coincidence of two independent computations**: it is the equation from which the potential's single coefficient, E_0 , is solved. One equation, one unknown. What that solving does deliver is that the potential of the medium **does not have a single adjustable coefficient**. In an ordinary elastic model that coefficient is measured in the laboratory; here it comes out written with π and with $\sqrt{6}$, and with nothing else. And both are already above, each with its provenance. The π comes from the floor, which is an average over the ripples the lattice admits, and where ripples are averaged π appears. The root of six comes from the ceiling, from the $\sqrt{2/3}$ of the crystal's maximum packing, which is the same root written another way. The coefficient ends up written, then, with the floor and the ceiling of the medium, and the floor and the ceiling are geometry of the lattice.

The **ceiling** comes from a theorem of geometry. The tightest way to stack equal spheres is the way oranges are stacked at a fruit stand —the face-centered cubic lattice, FCC—. Johannes Kepler conjectured in 1611 that there is no denser one, and Thomas Hales proved it in 2005. Treating each grain as a sphere, the ceiling is how many times the grain density of the diamond lattice, n_{diamond} , fits into that maximum density, $n_{\text{FCC}}^{\text{max}}$; and it comes out squared because the density of the medium goes as S^2 :

$$S_{\text{max}}^{2, \text{geom}} = \frac{n_{\text{FCC}}^{\text{max}}}{n_{\text{diamond}}} = \frac{8}{3} \sqrt{\frac{2}{3}} = 2.1773242,$$

and its square root is the maximum modulus —the cap on the compression, which the medium approaches without reaching—, $S_{\text{max}} = 1.4756$. And the coefficient $1/40$ of F1's flexural term comes from that same lattice, from its four neighbors per cell.

The check. The solving returns a number, and that number could have been useless in three different ways. It could have come out **negative**, and then the floor would in fact have been a peak and the medium would not rest there. It could have come out a million times larger, which would have shown that the lattice and the well do not live on the same scale. It comes out positive and of size one, not of size a million. And it could have left **two** floors instead of one, leaving undecided which of them is the vacuum; on sweeping the whole physical interval there is exactly one crossing.

What this changes. In any material physics describes, the floor and the ceiling of its deformation are data: they are measured in the laboratory and put into the equation. Here both are read off the shape of the crystal, and the shape of the crystal is not postulated either: it is fixed by the minimum of F1. No number in this chain is added: they all come out of it.

5. The two qualities of each point: how much it compresses, and which way it spins

And how does one describe what happens in the Pleno? With two pieces of data at each point, and no more —the two of the formula $\Psi = S \cdot e^{i\theta}$ —:

- **How compressed it is** —this is the S of the formula—: how much substance is packed at that point, its *compression*. The program calls it the *modulus* of the field: the length of the arrow. That is its name in the boxes and in the corpus. Its square is the density of the medium there. It goes with the square, and not with S itself, for the same reason as any wave: a swell of twice the height does not carry twice the energy, but four times. At rest, the compression has a background value; where there is “something,” a particle or a clump of matter, it departs from that background.
- **Which way it is spinning** —this is the θ of the formula—. The Pleno has, at each point, a kind of spin orientation, like the hand of a tiny clock. Turning all the hands at once changes nothing; what has an effect is how that orientation changes from one point to the next: if they all point the same way, the medium is calm; if it rotates and that pattern moves forward, that is a wave traveling.

With these two qualities —compression and spin— almost everything is understood.

The compression, moreover, never reaches the extremes. It cannot drop to zero, because the medium cannot empty out, nor rise without end, because the substance admits no packing tighter than its maximum.

Those two limits are the two walls of a well. If one plots how much energy each degree of compression costs the medium, out comes a curve with two walls and a bottom between them. Below the lower wall the medium cannot go down, above the upper one it cannot go up, and at the bottom, between the two, is where it rests.

The well, and why the medium cannot leave it

[DERIVED]

The two walls of the well come from two terms F1 already carries within, and between them lies the bottom where the medium rests.

Three pieces add up to the potential of the medium: the **elastic** one, the cost of compressing it, which carries the scale E_0 ; **Klauder**’s, the cost of approaching zero, which bears John Klauder’s name because it comes out of his affine quantization; and **Gent**’s, the cost of approaching the ceiling, which bears the name of Alan Gent, who wrote it in 1996 for rubber. Together they give the effective potential $V_{\text{eff}}(S)$, which says how much energy each degree of compression of the medium costs. The elastic one and Gent’s are the two halves of F1’s $V(S)$, the one that sustains the stable configurations and the saturation A6 demands; Klauder’s is the fourth term of the equation, written apart because its origin is quantum and not elastic. Effective means that the three add up into a single curve, and that curve is the one the medium feels.

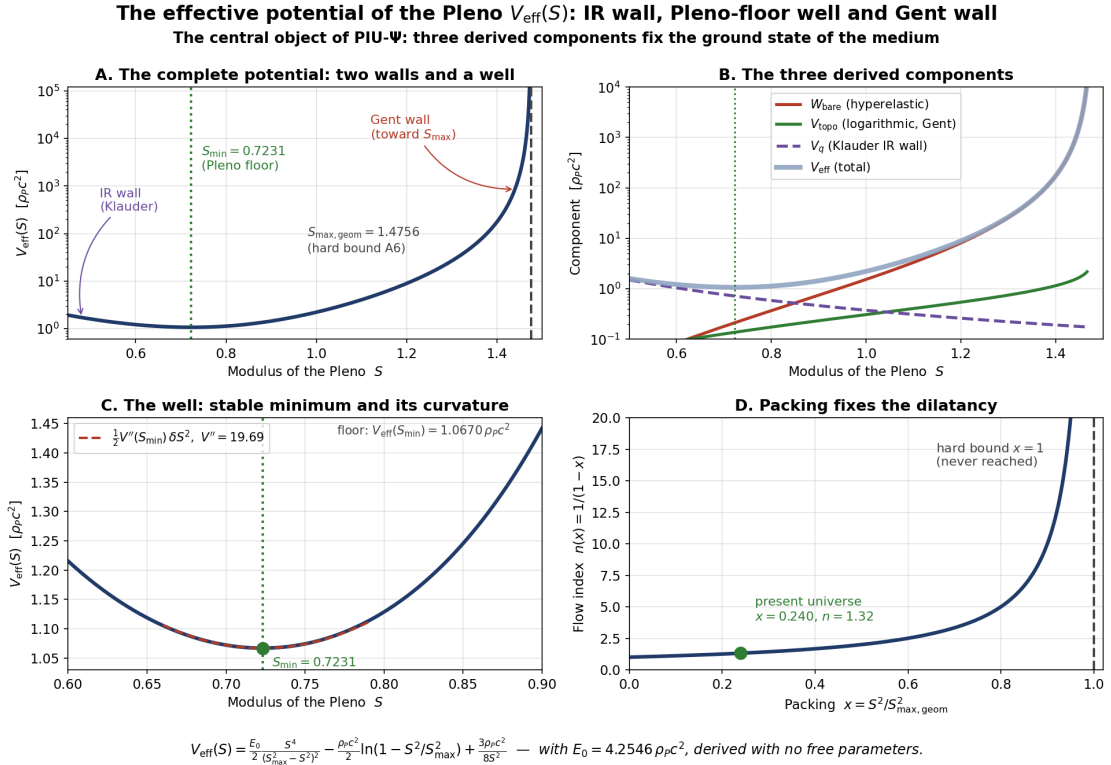


Figure 4: The effective potential of the Pleno, the energy each degree of compression costs: the lower wall preventing the medium from vanishing, the bottom of the well where it rests today, and the hard wall preventing endless compression. All three are derived, without a single knob to turn.

The **lower wall** comes from the Klauder term, of quantum origin, which grows without limit as the modulus approaches zero, so that the medium never gets to vanish. That quantum origin shows clearly in a familiar case: an electron shut in a box cannot stay still, and the narrower the box, the more it stirs. Forcing the modulus never to be negative is shutting it against a wall, and the energy of that confinement soars as it nears zero. The **upper wall** comes from the logarithmic Gent term—the form used to describe a rubber reaching its stretching limit—which grows without limit as S approaches its saturation value: the cost of compressing the lattice runs away as it approaches maximal packing, and that maximum is not reached either.

Between the two walls lies the **bottom**, and there the medium rests today. Its position is $S_{\text{min}} = 0.7231$ —the same number the lattice gives—and how tight that bottom is (the curvature of the well at that point) is

$$\xi = \frac{V''_{\text{eff}}(S_{\text{min}})}{\rho_P c^2} \approx 19.69.$$

The two primes in V'' mark that what is measured there is the curvature—how much the curve bends at that point—and not its height nor its slope. The result is a number without units, of the kind that come out the same measured in meters or in inches, and it says how strongly the well brings the medium back to its rest compression when something displaces it: a narrow bottom brings it back strongly; a wide one, barely.

The yardstick compression is measured with $S = 1$, the value to which the density ρ_P corresponds exactly. Measured against that yardstick, the compression of the medium rests at 0.72 and never goes beyond 1.48. And since the density goes with the square, in its rest configuration the Pleno holds 52% of that reference density: $\rho_{\text{ground}} = \rho_P S_{\text{min}}^2 \approx 0.5229 \rho_P$.

What this changes. When a model needs a potential, the usual procedure is to choose it from a family of possible shapes until the numbers come out. Here there is no choosing: the three pieces are derived and the energy scale, $E_0 = 4.2546 \rho_P c^2$, comes out in closed form in π and $\sqrt{6}$, with not a single free symbol.

6. A firm medium that hardens with haste

The Pleno has two distinct ways of resisting deformation, and from each springs a famous consequence of physics. The first we can call its *firmness*; the second, its *resistance to abrupt change*.

Firmness: how much the medium yields when you push it. A good way to measure how firm something is, is to see how much it yields when you press it. Sink your finger into a pillow: it sinks a lot. Rest the same finger, with the same force, on a wooden table: it barely yields. The pillow is soft; the table, firm. “Firm” means no more than that: that for a given push, it yields little.

The Pleno, even at rest as it is today, yields very little when something pushes it. And it is the firmness of a *relaxed* medium: today it rests at the bottom of its well. From this firmness at rest comes the weakness of gravity.

Resistance to abrupt change: why the speed of light exists. That firm medium normally behaves like an elastic solid: deform it a little, and it recovers its shape, like a spring. But it also has a character that depends on *haste*: the faster it is forced to deform, the more it resists, and as it nears a maximum haste its resistance grows without limit.

Everyday substances do exactly this. Cornstarch mixed with water: strike it suddenly and it behaves like a solid, and you can even run across it; push it slowly and it flows between your fingers. Its resistance depends on how fast you force it. The Pleno is not a liquid at rest like cornstarch, but it shares its law: its resistance, too, grows with haste, and that is what lies beneath the light limit.

A moving body makes its way through the medium. A particle, in the Pleno, is a *knot*: a twist of the medium itself that winds around on itself and that no pull undoes, like a knot tied in a closed loop of rope. The knot holds together, and it is the surrounding Pleno that gives way ahead and recovers behind. The faster it goes, the faster it has to give way. Approaching the speed of light means forcing the medium to deform ever faster, and the medium hardens so much that it becomes impossible to push it further. The light barrier thus gains a mechanism: it is the point where the Pleno jams, and what it costs to approach it can be computed exactly.

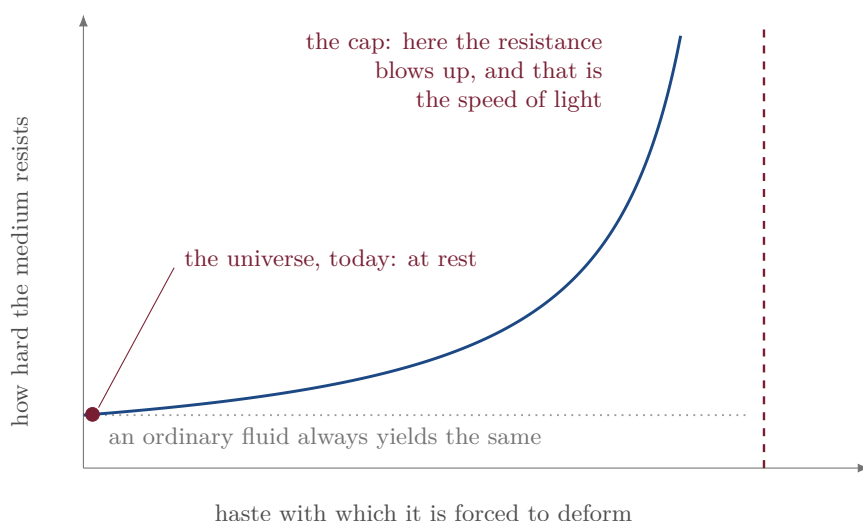


Figure 5: The Pleno’s resistance curve. The faster it is forced to deform, the more it resists, and as it nears its cap the resistance blows up: that is where the speed of light lies. Today’s medium is at rest, at the foot of the curve, where it behaves like an ordinary fluid.

That is inertia. A knot holds itself up: the energy it stores is its mass, and keeping it still costs

the medium no fresh work. What costs is shifting it. At constant speed that relay —giving way ahead, recovering behind— runs always at the same rate and asks for nothing new; accelerating is demanding it at a different rate, and that the medium charges for. Inertia is not, then, something the body carries inside, but what the medium charges for remaking its profile at a given rate. And that charge is not fixed: it grows with haste, along the same curve as in the figure, which is why accelerating costs more and more as the body approaches the speed of light.

And yet motion does not slow down. If advancing forces the medium to rearrange without pause, one would naturally expect a body to shed energy along the way and eventually stop—that a planet would have been slowing for aeons—. It does not happen, and the reason lies in which part of that rearrangement is paid for in heat. Moving a body costs the medium three distinct things: remaking its profile, which is inertia; remaking it fast, which is that same stiffening, relativity read in the material; and internal friction, the only one of the three that dissipates energy and really slows things down. That third one is charged only when the profile changes abruptly, over distances the size of the grain. A planet's is extremely smooth: it is spread over some 10^{34} grains, so each one takes a minute rearrangement, and the friction that results is one part in a one followed by seventy zeros (10^{-70}): zero for all purposes, and at any speed. That is why ordinary motion is not paid for in heat: the first two costs the medium stores and gives back, and the third, the only one that would dissipate them, never comes due.

Why there is a speed limit

[DERIVED]/[SLD]

The medium's resistance grows with haste up to a cap; read in terms of velocity, that curve is the Lorentz factor, and the same haste, read in the whole universe, is the rate of its expansion.

Every material has a curve saying how much it resists according to how fast it is deformed. The Pleno's is

$$n(x) = \frac{1}{1-x}, \quad x = \frac{\text{rate of deformation}}{\text{maximum rate the medium admits}},$$

the curve of a *dilatant* fluid, the family cornstarch belongs to. The n is the medium's resistance index: it equals 1 in an ordinary fluid, such as water, and in a dilatant one it grows with x and, as x approaches one, soars without bound; that one is not reached. It is a multiplier: it says by how much one has to multiply what deforming the medium unhurriedly would cost in order to know what deforming it at haste x costs. The maximum rate is one complete change per cell in the time light takes to cross it, and it bounds the deformations that change the shape of the medium. The form $1/(1-x)$ comes out derived from Gent's wall, as the medium's response to how tightly packed it is; reading it as a response to haste is a constitutive step, and what is computed with it carries the label [SLD].

That is what the light limit consists of. Accelerating a body means forcing the medium around it to reorganize ever faster, that is, raising x . The energy that costs grows with the resistance of the medium, and that resistance soars as x approaches one. Causality—that nothing can influence anything else faster than a signal takes to arrive— forbids passing c , and rheology—the study of how materials deform— says what approaching it costs: an energy that runs away without bound as the speed approaches c , which is exactly what the Lorentz factor says, the one Hendrik Lorentz wrote in 1904.

What is computation and not reading: the factor $1-v^2/c^2$ comes out of F1 itself as soon as one writes a deformation that travels—nobody puts it in by hand—, and the resistance of that deformation grows as the square of the Lorentz factor, $\gamma^2 = 1/(1-v^2/c^2)$. [DERIVED]

For a body moving at speed v , the relative haste is read as the square of its velocity measured in units of light, $x = v^2/c^2$, and with that reading the medium's resistance index is γ^2 : relativistic inertia and the dilatant hardening of the Pleno are the same function. From the same computation, with what the medium contains at each point, relativistic momentum and energy are read off, $p = \gamma mv$ and $E = \gamma mc^2$. The growing resistance to accelerating towards c , which in relativity is stated and accepted, is here a material hardening as it approaches its limiting rate of deformation. [SLD]

That same variable, formed with the rate at which the volume of the entire universe changes—which

is the Pleno deforming on the largest scale there is—, gives an exact identity:

$$|H| = \frac{x}{3}.$$

The H is the rate of the expansion: how much two points of the universe separate per second for each unit of distance that already lies between them, what astronomy calls the Hubble constant. The relative haste of the medium *is* three times the rate at which the universe expands, with that rate measured in units of the medium’s maximum rate. And the three is the three directions of space. As it stretches, the medium conserves its amount of substance: if it stretches equally in all three directions, the volume grows with the stretch multiplied three times by itself, and the compression has to drop accordingly. Putting that computation in terms of rates —how much the volume changes per second against how much the compression changes— leaves exactly one third between the two.

[DERIVED]

The identity translates haste into expansion rate, and it does not carry the light cap over to the expansion. That cap bounds the deformations that change the shape of the medium, and a universe stretching equally in every direction changes its size, not its shape. What sets how fast it expands is the energy the medium carries; and what keeps its beginning from being a point of endless density is the upper wall of the well, which bounds how far the medium is compressed, not how fast it changes.

The check. That the firmness of the medium and its causal structure are measured with the same c is not a coincidence the computation discovers: it is exactly what A3 asks for, and F1 is written to respect it. A Lagrangian with different temporal and spatial coefficients —a medium with two yardsticks— would give waves traveling at a speed different from that of their own causality, as happens in an ordinary crystal, which sound runs through at one speed and light crosses at another. That medium can be written down, and it is precisely the one A3 excludes. What is *not* postulated is what comes afterwards: from that single yardstick follow the Lorentz factor, the resistance curve read in terms of velocity and the identity between the haste of the medium and the expansion, and none of the three was obliged to come out with the form it does.

What this changes. In relativity, that nothing exceeds the speed of light is a property of spacetime: it is stated, it is accepted, and the energy it would take to exceed it is computed —but there is nothing that resists, only a rule that will not let itself be broken—. Here there is something that does resist, and it is the material. Accelerating a body forces the medium around it to reorganize ever faster, and the Pleno belongs to the cornstarch family: the faster it is deformed, the harder it gets. It is that hardness that runs away on approaching the cap, and its curve, read in terms of velocity, is the Lorentz factor’s. And the same haste, read at the scale of the whole universe, is the rate of the expansion.

7. Time: not a stage, but the pulse of the Pleno

We are used to thinking of time as a river that runs on its own, independent of everything, and of the things of the universe as boats floating on it. First comes time; then, what happens within. In the Pleno that image is inverted.

Here time does not exist “on the outside.” There is no prior river. What we call time is how much the Pleno has changed: the count of its accumulated changes, measured against the only reference rhythm there is —the maximum haste with which the medium can change, the same one that sets the speed of light—. That rhythm is not a duration but a tally: the medium cannot make more than one complete change per cell in the time light takes to cross it, and what gets counted are complete changes, not seconds. A second is an enormous number of those steps. Think of a clock that was all there is: it would not measure a time that was there anyway, because there would be no outside for such a time to be in; its ticking would be time, counted beat by beat. The Pleno is like that: it does not age within time; its aging is time.

That inversion dissolves questions that seemed unfathomable. “What was there before the universe?” or “how fast does time pass?” turn out to be ill-posed questions —like asking where the whole universe is, when “where” only makes sense inside it—. There is no “before” without

a Pleno that changes, because “before” is itself a measure of change; and there is no “speed of time,” because there is no second external clock against which to time the first. Time is not a container that can be filled or emptied: it is the trace the substance leaves as it transforms.

And that unties one of the knots of quantum gravity. When the quantum equation of the whole universe is written down—that of John Wheeler and Bryce DeWitt—, time disappears from it: there is no clock outside the universe to measure it against. In the Pleno that is what one expects, because time was never outside: it is the correlation between one part of the medium that acts as a clock and the rest, the mechanism Don Page and William Wootters described in 1983. Correlation means that two parts change together, so that the state of one tells the state of the other. That it is three o’clock does not assert that there exists an instant called three o’clock: it asserts that the rest of the medium is in the configuration that goes with the hand in that position.

Three things that at first sight look different turn out to be one: the accumulated change of the Pleno, the history of the expansion of the cosmos, and the very passage of time. They are the same count read three ways, because measuring time is counting how much the medium has changed, and the expansion is that same change seen at the largest scale there is.

From that way of counting there also follows something physics usually presents as a brute fact: that a moving clock runs slow.

There is a rhythm that never varies, and it is not the haste of the previous section. That one compared the deformation of the medium with the maximum it admits, and runs from zero to one. This one is measured against each thing’s own time: the total change of a configuration, counted against its own time, is always the same, because its proper time is nothing but the count of that change. Everything that exists therefore changes at the same total rate—including what looks still—, and what gets shared out is what that change is spent on. Part goes into moving—into remaking the profile a little further along, the same relay as inertia—, and what is left over is internal change: the change a clock counts. At rest, the whole allowance is internal and the clock runs at its full rate. In motion, part of the allowance goes into advancing, less is left for the inside, and the clock reads less.

Time does not “dilate,” then, the way rubber stretches: what happens is that the total change is bounded and has to be shared out. And at the extreme, light spends its whole allowance on advancing. No internal change is left to it, and that is why it has no clock: between leaving a star and reaching a telescope, however far it has traveled, no proper time has passed for it at all. The Lorentz factor, which relativity introduces as the rule for that sharing, is here the count of how much change is left for the inside.

8. Gravity: not a force that pulls, but the medium relaxing

For centuries we thought of gravity as Newton described it: an invisible force one body exerts on another, pulling it at a distance. The Earth “pulls” on us; the Sun, on the Earth. It works wonderfully for calculation, but leaves an uncomfortable question: how does one body pull another that is far away, without touching it, across the void?

A century ago, Einstein overturned that image and answered, in large part, that question. In his general relativity, gravity is not a force that pulls: it is the *shape* of space. A mass deforms the space around it—curves it—, and other bodies, as they move, feel no pull at all: they simply follow the straightest path that curved space allows them. The usual image is a heavy ball on a taut sheet: it sinks the surface, and a marble passing nearby falls toward it not because the ball attracts it, but because the ground beneath the marble is tilted. Einstein thus dissolved the mystery of the “pull at a distance”: there is no pull, there is geometry. The Earth does not tug at the Moon; it bends space, and the Moon follows the curve.

PIU- Ψ answers the question Einstein left open. Einstein tells us *that* space curves, and describes with exquisite precision *how* it does. But he does not say *what* space is, nor *why* it can curve: he takes it as the ultimate stage, given. Space is not the final floor of reality: it is a description of how the Pleno behaves seen from far away. What Einstein calls “the curvature of space” is, seen up close, the deformation of the Pleno. For Einstein, geometry is the *starting point*; for PIU- Ψ , it is the *finish line* —something that emerges from the medium, not something to be assumed—. Einstein geometrized gravity; PIU- Ψ explains what that geometry is made of. And when one does the math, Einstein’s equations reappear intact inside PIU- Ψ : they are *derived*.

In the Pleno, gravity arises from the elasticity of the medium, and it is understood by looking at it from its two sides: from the mass, and from the Pleno.

From the mass, gravity is the tail of what the mass is. A mass —a star, a planet, yourself— is knotted Pleno: a region where the medium departs from its rest. And that deformation does not end at the edge of the object: it weakens with distance and reaches its whole surroundings. What we call a body’s gravitational field is the outer part of that same deformation. There are not two things, the body on one side and its field on the other: there is a single profile, tight at the center and ever fainter outwards.

From the Pleno, gravity is the medium going where it costs least. Holding a mass costs: the medium has to be kept deformed around it, and the medium always tends to return to its rest. But that cost is not set by the mass alone. It is set as well by how the medium already is at the place where the mass is put.

If it is put where another mass has already deformed the medium, part of the work is done, and holding the second one costs less. The closer it is, the more deformed the medium is there, and the more is saved. That saving goes as one divided by the distance, which is the exact form of the Newtonian potential. And lowering the cost is the only thing an elastic medium does: lowering it, here, means coming closer.

Both views say the same thing. Like every elastic medium, the Pleno tends towards the configuration that costs it least, and the way there is to bring the two masses together. What we call “gravitational attraction” is the overlap of the two deformations lowering the energy of the whole. And unlike the marble on the sheet, which needs a second gravity to push it downhill, here none is needed: what goes downhill is the energy of the medium itself.

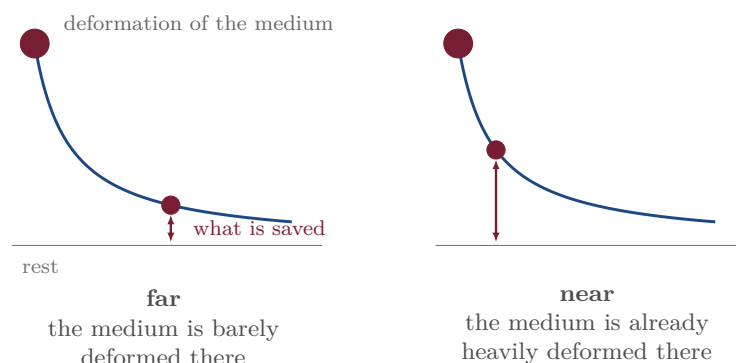


Figure 6: Why two masses come together. The curve is the deformation the first mass holds around it: large right against it and ever fainter with distance. Holding the second mass costs less the more deformed the medium already is where it is put, and the segment marks that saving. The closer, the larger it is: it grows as one divided by the distance, which is the exact form of the Newtonian potential.

And inertia is that same profile, charged for moving it. What it costs to accelerate a body is that the medium must remake its profile at a given rate, and the measure of that cost is

the energy the body retains; what gravity reads from that same body is also its energy. From this it follows, with nothing to postulate, that the mass that weighs and the mass that costs to accelerate are one and the same: a single energy, read twice —by its tail, which is gravity, and by its relocation, which is inertia—.

Think of cereal flakes floating in a bowl of milk. Each flake has weight, and the surface tension holds it without letting it sink altogether, so the surface curves a little around it and a dimple is left. That dimple does not end at the edge of the flake: it goes on around it, ever fainter.

When two of them are close, each one is sitting on the slope of the other's dimple, and on a slope one slides. The two drift toward each other on their own, without touching, until they meet. Nothing pulls them: being in the other's dimple comes cheaper than being on the flat surface, and that is enough. The Earth's gravity does two things there —it opens the dimple and it pushes down the slope—, and it also sets how far the effect reaches: a few millimeters, because beyond that it flattens the surface.

In the Pleno there is no second gravity to borrow. The dimple is the mass, because a mass is the medium itself deformed, and what pushes down the slope is that the medium seeks its least cost. And the effect is not cut off at any distance: it only weakens as the inverse square of the distance, because it is spread over an ever larger sphere.

And so Newton's old uncomfortable question does not even arise: nothing pulls across the void, because there is no void; there is a continuous medium that explains everything by contact, point to point.

And how weak is gravity? More than intuition suspects. A simple fridge magnet, the size of a coin, lifts a paperclip and so beats the gravitational pull of the entire planet. Between two protons, the gravitational attraction is some 10^{36} times feeble than the electrical repulsion —a one followed by thirty-six zeros—. And yet it is gravity that shapes the universe at large scales.

How can the weakest give shape to the galaxies? Through its reach. The other forces, for all their intensity, either act only at tiny distances —the nuclear ones do not reach beyond the nucleus of an atom—, or cancel themselves out: in matter there are as many positive as negative charges, and their electric pulls almost entirely nullify each other. Gravity, by contrast, never cancels (there is no “negative mass” to counter it) and its reach has no limit: it adds and adds across cosmic distances, from planet to star, from star to galaxy. Thus the weakest force of all, precisely by acting without canceling over immense distances, ends up being the one that molds the entire cosmos.

That colossal weakness is one of the great unsolved puzzles of physics: no one knows, in the usual framework, why gravity is so extraordinarily weaker than the rest. It is accepted as a fact, an “it is so.”

If gravity is the medium relaxing, one would expect a very firm medium to produce a very strong gravity: a stiff spring pulls harder than a soft one. Just the opposite happens, and the reason lies in who produces the deformation. It is not there in advance: the mass produces it. A given mass pushes with a given force, and what the medium yields to it is that force divided by its firmness, so the firmer the medium, the less it yields.

And gravity is what is saved by bringing two of those yieldings together. The saving is computed in two steps, and each one brings the firmness in from a different side.

First step: how much the medium yields. A medium a thousand times firmer yields a thousand times less to the same mass.

Second step: how much is saved by that yielding. The saving goes with the square of the yielding, so a yielding a thousand times smaller saves a million times less; and it goes once with the

firmness, which multiplies it back by a thousand.

A million times less, multiplied by a thousand, is a thousand times less. A medium a thousand times firmer gives a gravity a thousand times weaker: the firmness, which came in from both sides, ends up dividing. That is exactly what the “gravitational constant” measures: not a force, but **how much the medium yields** when a mass is placed in it —and that yielding is what a distant observer reads as curvature of space—. That the number is minuscule says the medium is extremely dense and at rest barely yields. That is why the firmness of the Pleno is not postulated: it is read off the measured weakness of gravity.

Newton’s constant as a structural identity

[DERIVED]

The gravitational constant turns out to be a property of the medium: its density and its grain.

Take two disturbances of the medium —two regions where the compression departs from its rest— separated by a distance r and compute, with F1, the energy it costs to sustain them. The mass of each one is that same energy divided by c^2 : a region that departs further from its rest stores more energy and weighs more. The result has the form $-GM_1M_2/r$ of the Newtonian potential, and on comparing the two no loose factor remains: the scale carried by F1’s kinetic term is c^4/G . Solving,

$$\rho_P c^2 \ell_P^2 = \frac{c^4}{G} \quad \Longleftrightarrow \quad G = \frac{c^2}{\rho_P \ell_P^2}$$

The gravitational constant is the speed of light squared divided by the density of the medium and by the square of its grain. Nothing else enters the formula.

The derivation gives more than a fit of units. With the density, the grain and c one can build a great many quantities with the units of G : it is enough to multiply that expression by any of the program’s pure numbers, such as ξ or $S_{\min}$. The units do not decide among them; the dynamics of F1 does: of all those combinations, the one it produces is $c^2/(\rho_P \ell_P^2)$, and no other. Sakharov’s induced action, in the next box, finds the same rigidity of the medium, $\rho_P c^2 \ell_P^2$, again, by an independent route.

Up to here, the derivation. Reading that constant in meters, kilos and seconds is a later step, the **calibration**: translating the density and the grain of the medium into human yardsticks. That translation is declared once, makes the grain of the medium the Planck length and leaves a **coefficient** one in front. The calibration takes nothing away from the derivation: it gives the human number its standing as calibrated. To put it to the test, a contrast number, κ_G , is placed in front of it —and another, κ_h , in front of Planck’s constant, $\hbar = \rho_P c^2 \ell_P^4$, which comes out of the same pair of density and grain and whose one the count of the spin does give—: the day the density or the grain of the medium is measured by another route, that one will be put to the test. Two constants of nature thus come out of two quantities of the medium, with no freedom to spare.

From it also comes the force scale of the medium, $c^4/G = \rho_P c^2 \ell_P^2 \approx 1.2103 \times 10^{44}$ newtons: the structural tension of the Pleno, known as the Planck force. And that scale fixes the coefficient of the Einstein-Hilbert action, $c^4/16\pi G = \rho_P c^2 \ell_P^2/16\pi$: the rigidity of the Einstein-Hilbert term is F1’s kinetic rigidity read in geometric language, divided by a pure geometric factor that contains no parameter of the Pleno.

One frontier remains. The formula says what G depends on; to have its number in meters, kilograms and seconds one needs to know what the density and the grain of the medium amount to in those units. That is a statement about the yardstick, not about the derivation: a constant with units has no value of its own until the yardstick is chosen, in this theory and in any other. What is calibrated are those two values, the density and the grain, and with G and $\hbar$ measured they give a grain equal to the Planck length. With the yardstick fixed once, the structure forces the rest.

Which channel carries gravity at a distance. The computation above reads the elastic response of the compression as if its reach had no limit. It has one: the well gives it a mass, and that response dies out within a quarter of a grain ($0.2589 \ell_P$). That is why the Pleno has no fifth force: the reach of that channel lies thirty (30) orders of magnitude below what the torsion balances of the Eöt-Wash group, which look for one, are able to see. What carries gravity at a distance is the shape mode of

the medium—the one that lengthens it in one direction and shortens it in the perpendicular one, the same as in a gravitational wave—, which has no mass, and its source is the energy each body contains. There is no charge there to normalize, and that is why it is there that the coefficient is fixed.

The check. The interaction energy has three pieces: the elastic cost of the terrain left between the two masses, and the coupling of each one to the deformation the other has already made. The elastic term cancels one of the two couplings, and the one that survives is the one that carries the negative sign, the attracting one. With the elastic term alone the sign would come out the other way round, and the medium would drive the masses apart instead of together.

What this changes. In general relativity and in the Standard Model of particle physics, G enters as a datum: it is measured and accepted, and neither of the two returns it from its own dynamics. Here it comes out as an identity of the medium, with the number in front equal to one, and the minuteness of its value stops being an enigma: it says that the medium is extremely dense and barely yields.

The rulers and the clocks we measure with are made of the same medium we measure. Where the Pleno is more deformed, a ruler laid there does not measure the same as one laid far away, and a second does not last the same. And nobody can step out of the medium to check it: all there is are local measurements, taken with instruments that the state of the medium affects.

Curvature is the name for what happens when those local measurements do not fit together as they would on flat paper. There is no need to imagine a space bending inside another: it is enough for the medium to be more deformed in some places than in others for the distances and the times measured from inside to stop adding up. Geometry is not the stage: it is the reading that the Pleno's disturbances make of the state of the medium.

Einstein's equations, by induced action

[DERIVED]

The whole equation of general relativity reappears, with its full coefficient.

The mechanism is the one Andrei Sakharov proposed in 1967: *induced action*. The medium vibrates ceaselessly down to the scale of its grain, and among those vibrations are those of its tensor mode: the deformation that lengthens it in one direction while shortening it in the perpendicular one, the same one a gravitational wave carries. That deformation is a rearrangement of the shape of the lattice: the cells end up closer together in one direction and further apart in the perpendicular one without any of them changing how much it is compressed. What vibrates is the shape of the pattern, not the compression: it is, once again, the spin of the medium, at the level that needs two directions to be described.

Curving the medium changes the frequencies at which its cells can vibrate, and with them the energy those vibrations hold even unexcited. That energy comes to depend on the curvature, and its first term grows in direct proportion to it. Add up all those vibrations—that is what integrating out the fluctuations means—, and what remains at large scales is the action of the geometry, term by term.

On the left goes that action. The sign $\int d^4x$ says that the sum runs over all of space and all of time; $\sqrt{-g}$ is the factor that makes that sum measure the same in a curved space as in a flat one; and R is the quantity that measures how much spacetime curves at each point. Applying to it the same Euler-Lagrange procedure as before returns the equations on the right:

$$\Gamma_{\text{ind}}[g] = -\frac{c^4}{16\pi G} \int d^4x \sqrt{-g} R + \mathcal{O}(R^2/E_P^2) \quad \Longrightarrow \quad R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}^{(\text{Pleno})}$$

The left-hand side is the curvature of spacetime; the right, what the Pleno contains at each point. It is Einstein's field equation, unretouched. The Greek subscripts of $R_{\mu\nu}$, $g_{\mu\nu}$ and $T_{\mu\nu}$ do the same thing the μ of ∂_μ did: they run over time and the three directions of space, so that each of those symbols is not a loose number but a table with one slot for each pair of directions. And the E_P in the term that follows the first formula is the Planck energy, the one a cell of the medium stores; that term collects the corrections from the grain, which count only when what bends is the size of a cell.

The coefficient comes out *complete*, not “of the order of”: the factor $c^4/16\pi G$ appears with its value, with G already derived as an identity of the medium. And that number does not come from adding up the vibrations: from there come the sign, the size and the fact that the gravitational wave mixes with nothing, but the sum, on its own, leaves the number in front depending on how it is cut off. The number in front comes from the matching with Newton’s law, already derived, without adding up vibrations or cutting anything off, and there the 8π of the equation comes apart into its two pieces: it is $2 \times 4\pi$. The 4π is the surface area of a sphere of radius one: the gravity of a mass spreads equally in every direction of space, like the light of a bulb, and Gauss’s theorem reads that measure of the sphere in the long-range response of the lattice itself, which at large distance falls off as one over 4π times the distance, up to a factor with no π in it. That the medium responds the same in every direction is not assumed either: the symmetry of the tetrahedron gives it. The 2 comes from the term $-\frac{1}{2}R g_{\mu\nu}$ on the left-hand side, which subtracts from the curvature in each direction half of the total curvature; that subtraction is called trace reversal. And solving the equation around a static mass one reads off the metric Karl Schwarzschild found in 1916, which says point by point how much a step in each direction really measures and how long a second really lasts.

The check. Without the trace reversal the same computation returns 4π and not 8π : the factor 2 is isolated by contrast, and that subtraction is what puts it there. And the 8π is not a local coefficient of the lattice. Everything the lattice fixes between neighbors at a finite distance carries π only in even powers—squared, to the fourth—or not at all; a lone π , like that of 8π , cannot come from there. It comes from the long-range response of the same lattice: the lattice fixes the scale of the rigidity, the kind of wave and its dispersion, and its response at large distance fixes the 4π .

What this changes. The curvature of spacetime is not a starting point here but the effective elastic action of a medium, and Einstein’s equations are what that medium does seen from afar. General relativity stands intact inside the program, as an effective limit and with its exact coefficient.

There is a consequence of all this that has already been measured. If gravity is the medium deforming, then a gravitational wave—those ripples of space that Einstein predicted in 1916 and that the LIGO observatory recorded for the first time in 2015—is not a separate entity: it is the Pleno itself undulating, just as light is. And the two travel at exactly the same speed. In an ordinary material that does not happen: in the rock of an earthquake, the waves that push arrive before the ones that shake sideways. Rock has two different firmnesses, one for being compressed and another for being sheared (slid sideways, like a deck of cards being fanned), and each wave sees its own.

In the Pleno there are no two firmnesses to share out: there is a single yardstick, c , and everything that travels through the medium without mass travels at that speed, however it undulates. Light and the gravitational wave are two undulations of the medium’s spin, both without mass—light needs one direction to be described; the gravitational wave, two, because it lengthens the medium along one and shortens it along the perpendicular—. Sharing a speed is not, then, an agreement between two things: it is the only thing a single yardstick allows. And even the correction the grain introduces at extremely high frequencies is the same for both.

In August 2017 there arrived at Earth, from the same collision of two neutron stars—the remains of dead stars, so tightly packed that a spoonful would weigh as much as a mountain—, a gravitational wave, recorded by the LIGO and Virgo detectors, and a flash of light, recorded by the Fermi and INTEGRAL space telescopes. They had traveled a hundred and thirty million years (1.3×10^8). They arrived less than two seconds apart, which bounds the difference between the two speeds below *seven parts in ten million billion* (7×10^{-16}). For the Pleno that coincidence is not a lucky datum: it is the only thing that could have happened.

9. Black holes: a limit, not an abyss

From the Einstein equations there comes, solving around a static mass, the geometry of black holes: the solution Karl Schwarzschild found in 1916, with its horizon at the distance $r_s = 2GM/c^2$. That the program *reproduces*: it comes out with the right radius and nothing retouched. The

program's own contribution begins where general relativity falls silent: inside.

In relativity, the horizon is defined by the escape velocity: the minimum speed at which something has to be launched for it to move away and not fall back —from the Earth it is eleven (11) kilometers per second—. The horizon is the place where that escape velocity equals that of light, so that nothing can get out any more. In the Pleno it is something more concrete: it is the surface where the escape velocity equals **the speed of sound of the medium**.

That collides head-on with something everyone has heard: that there is no sound in space, that a scream does not carry through the vacuum. And in ordinary physics that is true. But sound does not mean “noise in air.” In physics, sound is *any disturbance that travels through a medium by pushing on its neighboring parts*: a squeeze that passes from here to the one next door, and from that one to the next, and so on. It happens in air, of course, but also in water —where it travels four times faster— and in steel, some fifteen (15) times faster than in air. Nor is its speed a whim: it is set by the firmness of the material and its density, faster the firmer and slower the denser. If there is no sound in space, it is not because sound is forbidden there: it is because there is no medium to carry it.

In the Pleno **there is always a medium**, because the medium is all there is. So the Pleno has a speed of sound at every point of the universe, including the space we call empty, and that speed is the speed of light: in F1, the same c that fixes the firmness of the medium also fixes the maximum speed at which a change can propagate, and that is why the medium's own waves travel at exactly the speed causality sets. That is what it means for the Pleno to be relativistic.

In ordinary matter the two speeds are nothing alike: sound in air travels at three hundred and forty (340) meters per second and light at three hundred thousand (300 000) kilometers per second, almost a million times (8.8×10^5) faster. That in the Pleno they are the same number is precisely what makes the two definitions of the horizon —relativity's, with the speed of light, and the medium's, with the speed of sound— describe the same surface.

The horizon of a black hole is, then, the surface beyond which no wave of the medium can carry a change outward. Inside, the medium goes on changing at its own rate, and light advances at c at every point; what is lost is transmission to the outside, not change. And nothing has to rush into a sink: what crosses the limit is the *compactness*, how much mass is enclosed for the size of the region, which at the horizon equals one. Physics has studied, since William Unruh proposed them in 1981, laboratory “acoustic black holes” —fluids that speed up until sound can no longer climb back against the flow—, but it treats them as an analogy for gravity. Here there is no analogy but an identity: there is only one medium, and its speed of sound is the speed of light.

In general relativity the collapse ends in a **singularity**: a point of infinite density where the equations stop meaning anything. It is the admission that the theory, within its own domain, stops working. And it happens under very general conditions: there are theorems guaranteeing it, those of Roger Penrose and Stephen Hawking.

In the Pleno it cannot happen, and the reason is one of material. The medium has a compression ceiling —the upper wall of its energy well—, and bringing it close to that ceiling costs an energy that grows without bound; the ceiling is never reached. The collapse, then, does not end in a point: it ends in a **saturated core**, with a finite density, pressed against the ceiling of the medium.

The density of that core is **the same for every black hole**, whatever its mass, because it is set by the ceiling of the Pleno and not by how much is thrown on top. And that ceiling is read with two numbers. The occupation of the core approaches, without reaching it, a maximum of two point one eight times (2.1773) the reference density of the medium, the Planck density. But what weighs in gravity is not the whole occupation, but how far the medium departs from its

rest, just as in the universe at large. With the rest subtracted, what gravitates is one point six five times that density (1.6545), and that is the number anyone able to weigh the core would measure. A black hole of ten solar masses and one of a thousand million have the same heart; what changes is their size.

And that interior is not a hot compressed gas but a **condensate**. A condensate is what happens when an enormous number of pieces stop behaving each on its own and start moving all in unison, as though they were one: it is what happens to helium when cooled until it turns superfluid, a liquid that flows with no friction at all and climbs the walls of its container by itself; or to a cloud of atoms cooled to a few millionths of a degree above absolute zero, which marches in step as a whole. What defines a condensate is not the cold but that every piece shares one state; cooling is merely the usual way of getting there. Here compression gets there: it is the entire medium in its saturation configuration, in unison and without the disorder of a gas. That is why the interior is cold, and the disorder of the black hole —its entropy— lives not inside but on the surface.

The whole object has two parts. The core holds a quarter of the mass; around it, a halo —a field that extends outward and weakens with distance— holds the other three quarters. And in the core the medium does not push outward, as a squeezed gas would: it pulls, like a taut rubber band, and that tension is what holds the object up against its own weight. Everything stays bounded: the density, the stresses and the curvature of spacetime, which has a ceiling, the same for any mass. From outside, the object is Schwarzschild's: the shadow the program predicts for Sagittarius A*, the black hole at the center of the Milky Way, measures fifty-three microarcseconds (53.2), and the Event Horizon Telescope (EHT) published in 2022 the measurement of its ring: 51.8 ± 2.3 .

The horizon grows in proportion to the mass; the core, with its fixed density, grows much more slowly, because at fixed density doubling its mass is doubling its volume, and doubling the volume enlarges the radius by only twenty-six percent (26%). As the mass goes down, the horizon shrinks faster than the core, and there comes a point where the saturated region can no longer enclose itself. Solving that condition gives a **minimum black-hole mass** —nearly three millionths of a gram (2.9×10^{-6} g), that of a grain of fine sand— below which none is possible. The full black hole, the one that holds light, begins somewhat higher, at some seven and a half millionths of a gram (7.6×10^{-6} g); below that second mass, the medium forms a compact object that does not trap light.

The minimum mass coincides with the point at which, according to Hawking's theory, a black hole would finish evaporating: Hawking showed in 1974 that black holes emit a faint heat and lose mass by emitting it, faster and faster the smaller they are. Two lines of reasoning that share not a single step —one thermal, through the heat the hole emits; the other geometric, because the core stops fitting inside its own limit— arrive at the same mass. The program does not correct Hawking: it reaches his same number through another door.

Nobody has seen the inside of a black hole, nor will soon: this is a prediction. But it changes what can be answered when someone asks what is in there. Where ordinary physics says “there the equations break and we need a quantum theory of gravity we do not yet have,” the Pleno says “there the material reaches its ceiling, and this is what is there.”

The saturated core, and the minimum mass that follows

[DERIVED]/[SLD]

If the material has a compression ceiling, inside a black hole there is a core of finite density, and a minimum mass follows from it.

The Schwarzschild metric comes from solving Einstein's field equation around a static mass, with its radius $r_s = 2GM/c^2$. That much is reproduction; the program's own begins in the interior.

The horizon as a sonic surface. The modes of the medium travel at c , and at the horizon the

escape velocity is c : the horizon is, exactly, the surface where the Pleno's Mach number equals one—the Mach number is the speed divided by the medium's speed of sound, the same one used to say an aircraft is flying at Mach 1—. The acoustic gravity physics studies as an *analogy* (Unruh's model) is here an identity, not a resemblance: $v_{\text{escape}} = v_{\text{sound}} = c$. There is no flow into a sink: what exceeds unity is the compactness $x_g = 2Gm(r)/(rc^2)$, with $m(r)$ the mass enclosed within radius r . **[SLD]**

The core. The hard bound of axiom A6 forbids compressing the medium beyond its maximum packing. The occupation has as its supremum $S_{\text{max,geom}}^2 \rho_P \approx 2.1773 \rho_P$; what gravitates is the excess over rest, and its ceiling is

$$\rho_{\text{max},g} = (S_{\text{max,geom}}^2 - S_{\text{min}}^2) \rho_P \approx 1.6545 \rho_P,$$

where S_{min} is the rest compression of the medium. It is the same ceiling that gives the upper wall of the well, universal and non-singular, and it does not depend on the mass of the black hole. No configuration reaches it: it is a supremum, and the figures that follow are its limiting values. In the core the stress is a tension, $p = -\rho_g c^2$; with it, a region at that density reaches compactness one at the radius

$$\ell = \sqrt{\frac{3c^2}{8\pi G \rho_{\text{max},g}}} \approx 0.2686 \ell_P.$$

The core holds $M/4$, and a halo of radial field, with a density falling as r^{-4} , holds the remaining $3M/4$. The curvature stays bounded at every point and for every mass: its Kretschmann invariant—the standard measure of how much spacetime curves—never exceeds $120/\ell^4$. It is a *regular* black hole, of the family Sean Hayward described in 2006. **[DERIVED]**

The minimum mass. Setting the radius of the saturated region equal to the Schwarzschild radius of the same mass, $r_{\text{core}}(M) = r_s(M)$, one solves for

$$M_{\text{min}} = m_P \sqrt{\frac{3}{32\pi (S_{\text{max,geom}}^2 - S_{\text{min}}^2)}} \approx 0.1343 m_P \approx 2.923 \times 10^{-9} \text{ kg},$$

with no free parameter: only the Planck mass—what a cell of the medium weighs—and the two numbers of the lattice. From

$$M_* = m_P \sqrt{\frac{81}{128\pi (S_{\text{max,geom}}^2 - S_{\text{min}}^2)}} \approx 0.3489 m_P$$

upward the object holds light and has its horizon at $r_+ \simeq 2GM/c^2$; below M_* it is a compact object without a horizon. **[DERIVED]**

The check. That the escape velocity and the speed of sound should coincide at the horizon is not trivial: in any ordinary fluid they are two different numbers, and they coincide only if the medium and causality are the same thing. And the minimum mass falls where Hawking places the end of evaporation. The two computations do not contradict each other: they say the same thing by routes that share not a single step. Hawking showed that a black hole emits a faint heat, that emitting it makes it shrink, and that the more it shrinks the hotter it gets and the faster it emits, until it is used up; that end lies at a certain mass. The program arrives at that same mass without speaking of heat: the saturated core shrinks more slowly than the horizon, and below a certain mass it stops fitting inside it. A thermal argument and a geometric one, made from different premises, arrive at the same number. And outside the horizon the object coincides with Schwarzschild: the shadow of Sagittarius A* comes out at 53.2 microarcseconds against the EHT's 51.8 ± 2.3 , at 0.6σ —six tenths of the typical error of the measurement—.

What this changes. General relativity predicts its own failure at the center of a black hole: a density that grows without measure and equations that stop meaning anything. The usual answer is that at that point a quantum theory of gravity that does not yet exist will be needed, and there physics stops. Here the collapse stops earlier, because the material has something to stop it with: as it approaches its maximum packing, the cost of compressing it further grows without bound, and no amount of weight on top is enough to overcome it. What is left inside is not a point but a core of finite density, the same in every black hole whatever its mass, with the curvature bounded throughout the object. And that ceiling was not introduced to solve this: it is the same one that raises the

upper wall of the well and the same one that makes the universe bounce. One single property of the material, paying in three different places. Of what lies inside there is as yet no measurement at all: it is a prediction.

10. The other constant: the spin of a grain

If the firmness of the medium gives the gravitational constant, the other great constant of physics—the quantum one, Planck’s, which sets the size of the quanta—comes from the other side of the field: from the spin.

The Pleno has grain: its tightest fold has a minimum size, and that size defines its cells. Each cell has its phase hand, and turning that hand costs the same as turning the mass of the cell: it has the same inertia.

And anything with mass that spins carries a well-defined amount of rotation—what physics calls *angular momentum*—, which grows with the mass, with how far from the axis it is spread and with how fast it turns; it is the quantity that is conserved when a figure skater pulls in her arms and spins faster. The fastest rate at which that hand can turn is one complete change in the time light takes to cross the cell. And the angular momentum of a cell turning that way *is* Planck’s constant. In an atom, the rotation of an electron around the nucleus takes only stepped values, in multiples of it, as Niels Bohr proposed in 1913. The unit of quantum rotation is the spin of a grain.

In the usual framework, gravity and the quantum are two separate theories, with two independent constants, and the problem of the century has been to marry them. In the Pleno they are two readings of the same medium: one measures how much it yields when you squeeze it, the other how much its smallest grain spins.

And there is a sign that they are not two things. The Pleno’s resistance to being bent is an elastic property, of the same kind as that of a sheet of steel: nothing in it sounds quantum. On computing it, however, it comes out written with Planck’s constant inside. These are not two numbers that resemble each other by chance: it is that the same term of F1 admits both readings—stiffness of the material, or quantum of spin—, and the two give the same thing. The elasticity of the medium is already a quantum property.

With that the circle closes. Gravity delivered an equation tying the density of the medium to the size of its grain; the spin delivers a second, different one between those same two quantities. Two equations and two unknowns are solved, and in solving them the medium is measured. There the program takes two numbers from the world—the measured values of the two constants—and in exchange obtains the density of the Pleno and its grain. The grain that comes out is exactly the Planck length, which had not been put in anywhere.

Planck’s constant is the spin of a grain

[DERIVED]

The quantum constant is the angular momentum of a single cell, and together with the gravitational one it closes a system of two equations.

A cell of the medium has a moment of inertia about its internal phase, $I_\theta = \rho_P \ell_P^5$. It is the usual recipe, mass times radius squared: the mass of the cell is its density times its volume, $\rho_P \ell_P^3$, and the radius squared supplies the two factors missing up to the fifth power. And it can spin at most at $\omega_P = c/\ell_P$ —one complete change in the time light takes to cross the cell—, because nothing in the Pleno changes faster than c . That turning the phase should cost what moving the mass costs is already in F1: its kinetic term splits into the stretching branch and the spinning branch, and both

carry the same coefficient in front. Its angular momentum is the product of the two:

$$\hbar = I_\theta \omega_P = (\rho_P \ell_P^5) \cdot \frac{c}{\ell_P} = \rho_P c \ell_P^4$$

As with G , the coefficient the derivation returns equals one. And with this second identity the system closes: two equations, G and $\hbar$, in two unknowns, ρ_P and ℓ_P . There, and only there, does the program's yardstick enter: two measured values for two unknowns. With the system solved, the grain and the density of the medium are fixed once and for all; and the grain that comes out is exactly the Planck length.

The resistance of the medium to being bent —F1's third term, a purely elastic property— turns out to equal $\gamma_\kappa = \hbar c/40$: a quantum quantity. These are not two numbers that happen to coincide: the coefficient of that term is $\rho_P c^2 \ell_P^4/40$, and $\rho_P c \ell_P^4$ is $\hbar$. And the floor of uncertainty comes out with the factor one-half quantum theory demands, plus a correction fixed by the size of the grain:

$$\Delta x \cdot \Delta p_{\text{medium}} = \frac{\hbar}{2} \sqrt{1 - \frac{3}{80} \left(\frac{\ell_P}{\sigma} \right)^2}$$

where Δx is the indeterminacy of position and Δp_{medium} that of the momentum the medium transports —momentum is how much motion something carries: its mass times its velocity, and what it costs to stop it—. The σ is here the width of the region in which the particle is confined—in this box, and only in it, that letter does not mean the typical error of a measurement—.

Heisenberg's relation pairs position with the momentum of the particle itself, and for that pair the floor of $\hbar/2$ **comes out intact**: the program neither lowers it nor retouches it. What the formula adds is a second floor, for another quantity: the momentum the medium transports, which is not the same observable. And there the correction *subtracts* instead of adding, so the product stays a little below. The sign matters, because the usual minimum-length proposals —the so-called generalized uncertainty principle— do the opposite: they add an excess, and with a coefficient fitted by hand. Here the sign is the opposite one and the number $(3/80)$ comes from two pieces that are not chosen either: how the lattice disperses and the shape of the wave packet itself. The size of the effect says everything about where it lives: in an atom it is one part in 10^{51} , and only at the smallest scale on which the medium relaxes does it become comparable to the floor itself: there the formula brings it down to half, $\hbar/4$.

The check. Two equations in two unknowns always have a solution; what is not guaranteed is their form. They come out by routes that share not a single step—one from the kinetic term, the other from the turning of the phase—, and a medium with other dynamics would tie G and $\hbar$ in another combination, so that the grain would not coincide with the Planck length. With F1, Planck's relation, $\ell_P = \sqrt{\hbar G/c^3}$, holds exactly.

What this changes. Max Planck introduced his constant in 1900 to account for the light a hot body emits, and its value has been measured ever since: it fixes the scale of all of quantum physics and no theory says why it has the value it has. Here both constants come out of the same medium and the same two scales, each with the number in front equal to one. What a century treated as two theories to reconcile is one material read from two sides.

11. The quantum world: the rules that stop being a starting point

Quantum mechanics works. It has been hitting the mark for a century and no measurement has contradicted it. What it does not do is explain itself: at its base there are five rules the theory takes as good—some it states at the outset, others it deduces from what it states—and which in no case say why nature is made in such a way that they hold.

- A particle's wave changes with time according to the equation Schrödinger wrote in 1926.
- Where a particle is and how much motion it carries cannot both be made sharp at once: it is the relation Werner Heisenberg stated in 1927.

- The probability of finding it somewhere is the square of the length of its wave function: it is the rule Max Born proposed in 1926.
- Two particles born of the same event agree more than any classical explanation allows, and they stop at one very particular number: 2.83.
- The electron is described by an equation Dirac wrote by hand in 1928, and it carries a turning of its own, spin, which does not stop even when the particle is still and which the theory attributes to it because experiments demand it.

In the Pleno all five come out of how the medium is made: out of its being made of waves, out of its phase being turnable entire with nothing changing, and out of its lattice sorting its cells into two alternating classes. None of the five has to be put in.

What Schrödinger left written. In 1926, Erwin Schrödinger wrote the equation that says how a particle's wave changes with time: how it moves, how it spreads and how it settles inside an atom. Solving it for the hydrogen atom returns, with nothing added, the energy steps spectroscopists had been measuring for decades.

With it we understand why each element emits its own set of colors and why atoms bond as they do; with it the spectrum of a molecule is predicted before it is made; and with it are computed today the materials of a transistor, the pigments of a screen and the candidates for a drug. All of computational chemistry is solving that equation.

What it does not say is what the wave is. Schrödinger never settled it, and the reading that prevailed leaves it as an abstract object of probability: something useful for computing, not something that is in the world.

Why that equation is the medium's. Write the Pleno as its arrow at each point—a length and an angle, $\Psi = S e^{i\theta}$ —and take the dynamics of F1 in the slow regime: on separating the length from the angle, the equation of the medium splits in two, one of continuity, which says the flow is not lost along the way, and one of motion for that flow. Those two together are, by an exact transformation Erwin Madelung found in 1926 and David Bohm developed in 1952, Schrödinger's equation. Not an approximation nor a resemblance: the same equation.

And with it comes what Schrödinger left open. The wave function is not an abstract object: it is the disturbance of the medium itself, with its length and its angle.

Why position and motion cannot both be sharp. How much motion a particle carries—its momentum: its mass times its velocity, and what it takes to stop it—is written in the rate at which its phase turns from one point to the next. A tight twist, a large momentum; a loose one, a small one. And a wave shut into a small region cannot carry a single rate: for it to die away outside that region, instead of spreading on, many different rates have to be superposed, and the narrower the region, the more rates it takes. To confine is to mix rates, and to mix rates is to lose the definite rate. In a medium made of waves the configuration that would have the position narrow and the twist sharp at once does not exist.

The minimum of that trade-off is exact, and it is half Planck's constant. And that constant is not a number brought in from elsewhere: it is the spin of a cell of the medium, written with its density, its grain and the speed of light. The floor on what can be known at once is thus written in the properties of the material itself, and not measured against a constant brought in from elsewhere.

The medium adds a second floor besides, and for another quantity: the momentum it transports itself, which is not the same observable as the particle's. There the grain subtracts instead of adding, and the product falls a little below. The sign matters, because the usual minimum-length

proposals do the opposite: they add an excess, and with a coefficient adjusted by hand. The effect is unobservable in an atom, and it shows only when the region narrows to the size of the grain.

Why probability is the square. The phase of the Pleno has a symmetry: turning every hand at once, everywhere and by the same angle, changes nothing that happens. And whenever something can be changed entire with nothing changing, there is a quantity that does not move; that is Emmy Noether's theorem. What that symmetry conserves here is a flow, and a flow is apportioned through space as the water of a river is apportioned among its branches.

That flow is made of two things, just as a river's is: how much water there is and how fast it goes. The second is the rate at which the hand turns. The first is the length of the arrow multiplied by itself, and not the length alone. The reason lies in the symmetry: to build a quantity that does not change when every hand turns, the arrow has to be paired with itself, because on pairing them the two angles subtract and vanish. And to pair a length with itself is to square it.

To ask with what probability the particle is found in a region is then to ask what fraction of the flow passes through it. The fractions sum to one because they share out a total that is conserved, and that total comes in whole units: a quantum carries one unit of flow, and the medium cannot change it. The Born rule stops being a postulate: it is the accounting of something conserved.

That is the medium's apportioning. For it to be the apportioning of the probabilities an apparatus measures as well, one more step is needed: that on detecting, the sample be taken without favoring some parts of the flow over others. It does not have to be assumed. The medium's own noise —the tremor its internal regulation introduces— drives any uneven apportioning towards the even one and holds it there, and it does so in a Planck time. The computation that shows it belongs to the same family as the one Ludwig Boltzmann used for gases, and that Antony Valentini carried over to the quantum: a measure of the mismatch that can only go down. That is why a departure from the Born rule has never been measured: any such departure would have been erased long before it could be seen.

And that total is conserved from one instant to the next as well: what physics calls *unitarity*, that the probability of something happening go on summing to one while the system evolves. In theories with terms like F1's flexural one, which charge for curvature, that guarantee is usually at risk: high-frequency solutions appear that would behave like particles of negative probability, the problem Tsung-Dao Lee and Gian Carlo Wick studied in 1969. In the Pleno they never come to exist. Those solutions would begin above the highest frequency the lattice can sustain, because there is no wave shorter than the grain, so they are not states of the medium; and the energy of each cell, enclosed between its two walls, has a floor. The evolution of the Pleno on its lattice is unitary exactly, with no need for approximations.

Why correlations reach 2.83 and no further. Two particles born of the same event are not two objects with a thread between them: they are a single configuration of the same medium, read in two places. That is why their phases stay related however far apart they are taken, and why measuring on one side does not alter what the other side sees on its own: nothing travels between the two apparatuses.

What does depend on the angle between the apparatuses is the agreement between the two measurements. That agreement falls off following a cosine, like the shadow of a turning arrow, because what is compared are two phases that turn. John Bell showed in 1964 that this agreement makes it possible to tell a world in which each particle brings its answer from one in which it does not, and in 1969 John Clauser, Michael Horne, Abner Shimony and Richard Holt turned it into a laboratory test: measuring each side in two different settings and combining the four comparisons that come out of it into a single number. There the two worlds part.

If each particle brought its answer written in advance, each comparison could only be a yes or a no, and that combination would not pass 2. With the medium's cosine nothing is gained by putting one comparison at its maximum, because the angle that favors three takes the fourth out of its place. The best that can be had is to share it out: the four angles half way, each comparison coming to a little over seven tenths —the square root of two divided by two—, and four times that is $2\sqrt{2} = 2.83$. And not a step further. Boris Tsirelson proved that ceiling in 1980 for the whole of quantum mechanics; here it comes out of the shape of the medium. Experiments have been measuring that combination above 2 for decades and never above the ceiling: Alain Aspect's, in 1982, gave 2.70, just what quantum theory predicted for his setup.

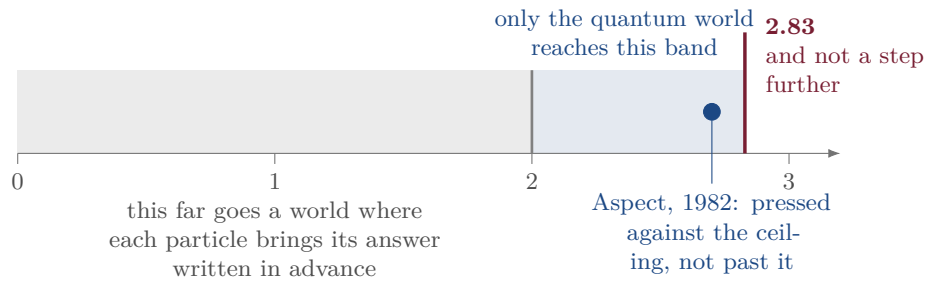


Figure 7: The ceiling on correlations. A world in which each particle carried its answer written in advance would not get past 2. The Pleno reaches $2\sqrt{2} = 2.83$ and stops dead. The experiments that test Bell's inequality have been measuring values between those two numbers for decades, and none above the ceiling.

What Dirac left written. In 1928, Paul Dirac was after an equation for the electron that would hold at speeds close to that of light too. He wrote it by hand, demanding two things of it: that it be compatible with relativity and that it describe a single electron properly. What came out brought spin thrown in —which George Uhlenbeck and Samuel Goudsmit had proposed in 1925 and which until then was added separately—, and a second solution with the energy sign reversed that turned out to be antimatter, found four years later by Carl Anderson. With that equation we describe today every electron of every atom, and on it rests quantum electrodynamics —that of light and electrons—, the theory that delivers the most precise prediction in all of physics.

What it does not say is why the electron behaves according to that equation and not another. Dirac built it to meet his two demands, and nothing in the theory explains where its form comes from, nor where the spin it carries inside comes from.

Where spin and the electron's equation come from. The question that decides the form of an equation of motion is how much energy it costs to move with each momentum. Drawn, that relation is a curve, and its shape says what kind of object one has. For a particle with mass moving slowly it is a parabola: doubling the speed costs four times the energy. For something massless, like light, it is a straight line. A straight line that rises equally steeply whichever way one looks is, seen in the three directions of space, a cone.

In any crystal the permitted energies do not form a continuum: they form bands, permitted strips separated by forbidden ones, which is what makes a material a conductor or an insulator. On the lattice of the Pleno there are whole lines where two bands touch, and the lattice, on its own, gets no further. What breaks those lines into isolated points is something the medium already has: the spin is tied to the direction one advances in —what solid-state physics calls spin-orbit coupling, whose form on the diamond lattice Liang Fu, Charles Kane and Eugene Mele wrote down in 2007—, and that tie, the only one capable of breaking them, is what breaks them. Around each of those points the cone appears. It is the same shape that makes the electrons in graphene propagate as though they had no mass, as Philip Wallace deduced in 1947. And that it should come out round is not free: that single condition fixes the strength of the tie, and leaves no other possibility.

The cone brings a problem with it. Near it the energy grows as the *length* of the momentum, and a length is a square root: that of the sum of the squares of the three directions. An equation of motion has to say how the field changes from one instant to the next, step by step, and a square root of a sum does not let itself be broken into steps: it ties the three directions into a single block.

The way out is to look for objects that, multiplied by themselves, give one, and multiplied crosswise cancel, because with them the root is written without a root. It is what mathematics calls a Clifford algebra, after William Clifford, who defined it in 1878, and it is exactly the language Dirac had to build to write the electron's equation. Not a similar one: the same. Dirac's equation is, then, the square root of the wave equation of the medium itself.

And spin need not be put in by hand either, because the medium already carries the two pieces it is made of. One is the phase hand, which after a full turn does not come back the same but with its sign reversed. The other is the lattice, which sorts its cells into two classes, A and B: each cell belongs to one or to the other, and its four neighbors always belong to the opposite one. Each piece has two values, and two pieces of two values give four combinations: a four-component object, which is the electron's, with its spin of one-half. Two routes arrive separately at that same object, the one through the crystal's bands and the one through these two pieces. The band route delivers the form; the route of the two pieces delivers besides that what turns is real spin, which transforms with space and time and not with the crystal.

The mass remains. The cone describes something that does not weigh, and the electron weighs. Mass enters the moment something tells one class from the other: the two branches of the cone then come apart at the vertex, the straight line curves, and the curve left is exactly relativity's relation between energy and momentum. What the medium delivers is the form of the equation, the spin and that relation. The electron itself is not one of those points of the crystal: it is a turn of the phase wound around a gap in the lattice, which glides through it without ever letting go; the equation is what describes it. How much each particle weighs is set by another computation, that of the size of each knot, which this one does not do.

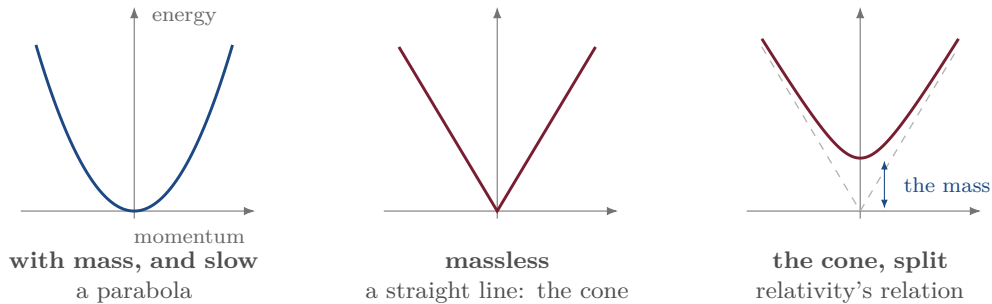


Figure 8: How much energy it costs to move with each momentum. For a particle with mass moving slowly, the curve is a parabola. For something massless it is a straight line rising equally whichever way one looks, and that is the cone: the shape the lattice of the Pleno leaves at the points where two bands touch. When something tells one class from the other, the two branches come apart at the vertex; that separation is the mass, and the curve left is relativity's relation between energy and momentum.

The equations the medium returns

[DERIVED]

The five rules come out of three things the medium already has: that it is made of waves, a phase that can be turned entire with nothing changing, and a lattice whose cells fall into two classes.

The Born rule. The phase symmetry gives the medium, by Noether's theorem, an exactly conserved current:

$$j^\mu = \rho_P c^2 \ell_P^2 S^2 \partial^\mu \theta.$$

What flows is the square of the length of the arrow, S^2 , times the rate at which its angle turns, $\partial^\mu \theta$, with the density of the medium and its grain in front to give the units. The square is not a choice: it is the only thing that survives turning every phase at once. The probability of finding the particle inside a region is the fraction of that current the region contains:

$$P(R) = \int_R |\psi_{\text{norm}}|^2 d^3x.$$

Read it this way: the probability P of finding the particle inside a region R is the sum, point by point over that region, of the square of the length of the arrow. That detection samples this apportioning is ensured by the relaxation of the medium: Valentini's H function, which measures the mismatch between the actual distribution and $|\psi|^2$, can only go down, and it vanishes at Born's apportioning. The algebra is exact; the diffusive form of the noise that drives it is [SLD].

The ceiling on correlations. Measuring two related particles at angles a and b gives the correlation $E(a, b)$, which equals one if the two measurements always agree and minus one if they always disagree:

$$E(a, b) = -\cos(2(a - b)).$$

The factor of two belongs to the polarization of light, which is the direction in which light shakes as it vibrates. It is the one polarized sunglasses take advantage of: such a filter, turned half a revolution, filters exactly the same. The ceiling comes out of that shape, and is the same with the factor or without it:

$$|S| \leq 2\sqrt{2} = 2.8284.$$

Here S is the Clauser-Horne-Shimony-Holt combination of four correlations, not the modulus of the medium, and the ceiling —Tsirelson's bound— is obtained by maximizing over the four angles, not by comparing with the known value. Classical physics cannot exceed 2; no experiment has gone past 2.83. And what each apparatus sees on its own does not depend on what the other does: no-signalling holds exactly, because there are not two systems communicating but one medium measured twice.

The equations of each regime. Each regime —each band of conditions in which the medium is looked at, slow or nearly at the speed of light— has its equation, and both come out of F1 as limits. At low energy, the Madelung separation (substituting $\Psi = S e^{i\theta}$ and splitting the equation into its real and imaginary parts) gives continuity and the Bohm equation, and that pair *is* Schrödinger's; over a condensate —a set of particles sharing a single state— it takes the Gross-Pitaevskii form, with one extra term that accounts for the medium getting in its own way. In the relativistic regime comes Dirac's.

And the Dirac construction delivers four things that were not asked of it. The first is that it is unique: a theorem of Pauli's says that all the ways of building it are the same one up to a renaming of the axes, so there was no second option that would have given a different physics. The second is what kind of spin comes out. What comes out is a spin under the rotations and the motions of the spacetime the medium itself produces, and not only under the symmetries of the lattice: it is real spin, of value one-half, and not a class label that resembles one, like the pseudospin of graphene. The third is that time ends up set apart from the three directions of space —it enters the computations with the sign changed—, and that does not have to be imposed either: the stability of the medium demands it, because with time and space of the same sign its energy would have no floor. The fourth is that the Dirac operator turns out to be the root of the wave operator of the phase sector, and the number that regulates it is the same 1/40 of the stiffness against bending.

And the evolution is unitary. On the lattice, the energy of each cell is bounded below, and its two walls —Klauder's, which keeps the medium from vanishing, and Gent's, which keeps it from being compressed without end— make it a well-defined operator; the high-frequency roots the flexural term adds, those of the Lee-Wick problem, begin at $\sqrt{20}c/\ell_P$, above the highest frequency of the lattice, $\sqrt{12}c/\ell_P$, and stay out of the spectrum. Total probability is conserved exactly, not order by order.

The check. This whole chain —from Planck's constant to the minimum of uncertainty, from the Born rule to the bound on correlations— *contains not a single calibrated link*: there is no parameter in it where a discrepancy could be absorbed, and any of these numbers could have come out wrong.

What this changes. Quantum mechanics has been working for a century with those five rules as a starting point: they are stated, or deduced from what is stated, they always hit the mark, and

nobody knows why the world is made in such a way that they hold. Here they are not stated, they are deduced from the material, and they arrive with their exact numbers —the factor of one-half, the $2\sqrt{2}$ —. What quantum mechanics predicts does not change; what changes is that it stops being a list of rules with no reason underneath.

12. The entire catalog, from a single medium

With a few ideas —an elastic crystalline medium that compresses and spins, firm yet able to flow— the program reconstructs the entire catalog of all that exists:

- **Particles** —a proton, an electron— are stable knots of the medium, and that is why they come in whole amounts: a knot is either there or not, and there is no half knot. Their mass is, roughly, the energy it costs to hold that knot.
- **Light** and all electromagnetic waves are waves of the medium's phase, with their two polarizations, with no need for a separate electromagnetic field.
- **Dark matter** is the same medium in another family of configurations, without the winding —the turns the phase makes around the knot— that anchors ordinary matter and that gives it its electric charge and, with it, its dealings with light.
- **Dark energy** is the part of the medium itself that moves in unison, at rest at the bottom of its well —not the bottom itself, which does not gravitate—, and it is the only component that does not thin out when the universe stretches.
- And at the largest scale of all, **the medium cannot be compressed without end**, so a contraction does not end in a dead-end catastrophe: the medium resists, gives back, and makes way for a new expansion in which it crystallizes and forms the matter we see today.

13. The forces and matter: the phase that circulates, the medium that knots

The Standard Model of particle physics describes light, the nuclear forces and matter with astonishing precision, but it starts from part of what would need explaining: the electromagnetic field, the charges of each particle and the three quarks of the proton —the pieces it is made of, and which have never been seen on their own— enter it as given structure.

What Maxwell left written. Until the middle of the nineteenth century, electricity and magnetism were two separate subjects, with their own laws, the ones Coulomb, Gauss, Ampère and Faraday had been finding. In 1865 James Clerk Maxwell showed that they are one: he completed those laws with the piece they lacked and gathered them into a theory that Oliver Heaviside later set down in the four equations in which it is taught today. The first says that electric charges are the wellspring of the electric field. The second, that there are no one-poled magnets: cutting one in half gives two magnets, not two halves. The third, that a changing magnetic field drives the electric one to circulate: it is what makes any generator work. And the fourth, that a current, or a changing electric field, drives the magnetic one to circulate: it is what makes any motor turn.

Together they do something more. On combining them a wave appears that travels on its own, and its speed is not measured: it comes out of the computation, from two laboratory constants. The number that came out was the speed of light, and with it the conclusion that light *is* an electromagnetic wave. Heinrich Hertz produced those waves in 1887, and that prediction is the reason radio exists. With those four equations we understand why a motor turns and why an antenna emits; with them we predict how much current a generator will give and how far a signal will reach; and with them are designed the electrical grid, radio, wifi, radar, magnetic resonance imaging and every optical instrument. A hundred and sixty years (160) later, no measurement

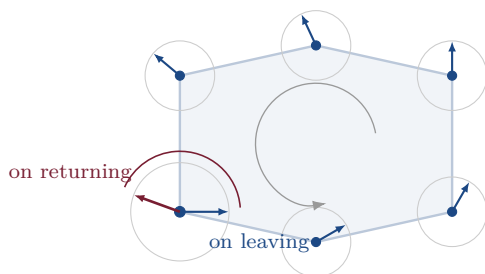
has contradicted them.

What those four equations do not say is where the field comes from. They describe what the field does and take the field itself as given; the energy it holds is written with a coefficient that is a matter of units, not a number the theory delivers.

Where light and Maxwell's equations come from. Each bond of the lattice carries a twist of its own: how much the phase turns on passing from one node to its neighbor. If those twists were only the difference between the hands at the two ends, on going around a closed loop they would all cancel and one would come back to the start with no mismatch at all. But the bonds have more freedom than the nodes: for each cell of the diamond there are two nodes and four bonds. Two of those four ways of twisting the bonds come from moving the hands of the nodes, and on going round they cancel. The other two do not: they are twists that circulate from bond to bond around the rings of the lattice, and on closing the loop they leave a mismatch, a net turn that does not close. Imagine carrying an arrow around the smallest ring the diamond offers—a hexagon of six bonds—, turning it at each bond by what that bond twists: you come back to the start with the arrow turned.

Each loop encloses a patch of surface lying in a plane, and for each pair of directions there is a family of loops with its own mismatch. There lies the difference between the two fields physics teaches separately. The mismatch of a loop lying between time and one direction of space pushes a charge even when it is still: that is the electric field. That of a loop lying between two directions of space acts on the charge only when it moves: that is the magnetic one. What in the books are two different fields is here a single thing, looked at in two families of loops of the same crystal.

you carry the arrow around a ring of the lattice and come back to the start



and the arrow does not come back as
it left: **that mismatch is the field**

Figure 9: Where the electromagnetic field comes from. An arrow is carried around the smallest ring of the lattice, a hexagon, turning it at each bond by what that bond twists. On returning to the starting point it does not come back with the angle it left with, and that mismatch, written as a field, is the electric one and the magnetic one.

That mismatch, written as a field, *is* the electromagnetic field, and deriving the equations of motion from its energy, as is done with any field, returns Maxwell's four equations for space free of charges: all the electromagnetism that travels, and light. The two ways of twisting the bonds that circulate are the two polarizations of light, the two directions in which it can vibrate, and both travel at c . With the charges—which are knots of the medium—acting as the wellspring of the field, the others are completed. The coefficient accompanying that field, $8/9$, says how much energy it stores per degree of mismatch, and it comes out of a count that can be followed step by step. The energy lives in what the loops enclose; to know how much a node stores it is enough to look at the planes its bonds open. A node has four bonds, and four things pair up in six ways: six pairs of bonds, and each pair opens a face, the small parallelogram whose sides are those two bonds.

What each face contributes is the area it encloses, counted with its orientation: a face lying broadside to the field contributes a lot, and one set edge-on, nothing. The six faces all have the same area, but they look in six different directions, and that is why each contributes something different. What is striking is what happens when they are added: they pair up two by two, and in each pair what one gains on one side the other loses on the other, so that in the end the sum does not depend on which way the field looks. It comes out the same in every direction. That sum, with the bonds measured in units of the grain, leaves $8/9$. The number is fitted to nothing: it comes from counting faces and adding areas.

The photon —the loose grain of light— comes out, moreover, massless. Turning the whole phase, everywhere at once, changes nothing, and turning it very slowly, from one end of the universe to the other, costs almost no energy. Having mass is precisely the opposite: that not even the longest wave comes free. The photon's does come free in that limit, and that is why it does not weigh; to weigh, it would have to break the symmetry that produces it. It is the theorem Jeffrey Goldstone proved in 1961: such a symmetry always leaves a channel with no minimum cost of entry —no *gap*, in the jargon—, and that channel is the channel of light. Experiments bound the photon's mass below 10^{-54} kilograms.

What Yang and Mills left written. In 1954, Chen Ning Yang and Robert Mills asked what happens if the internal symmetry a force rests on is of the kind that does not commute, that is, of the kind that gives different results depending on the order in which it is applied. The answer was a family of equations that contains Maxwell's as the simplest case, and that turned out to be the form of the two nuclear forces: the strong one, which holds the nucleus of every atom together, and the weak one, without which the Sun could not burn its hydrogen. The forces of the Standard Model of particle physics are all written as Yang-Mills theories.

What those equations do not say is which symmetry it is. The group is chosen because it reproduces what is observed, and the numbers that go with each force are measured.

The nuclear forces, from a richer spin. Each cell of the diamond has two nodes, one of each class, so what the medium carries from cell to cell is not a single hand but a pair; and the bond of F1 mixes the two. Turning a pair like that is of a richer kind, one in which the order of two rotations changes the result. It can be checked with a book on the table, cover up and spine to the left. Turn it a quarter turn on the table, as if it were a steering wheel, and then tip it over toward you. Now undo all of it and do the two things in the opposite order. The book ends up facing another way, with the same two turns. The rotations of space are like that, and mathematics says they form a non-commutative group. With an object of that kind, the same construction of the field adds a term, and that term measures exactly what the book has just shown: how far the result departs when the order of the two turns is swapped. With it, the construction returns the structure of the Yang-Mills equations, the form the nuclear forces take.

With them comes a rule physics knows well and does not explain: which combinations of quarks can exist on their own. Each quark carries a third of a turn of the color phase —the charge of the strong nuclear force, not the electric one—, and a third of a turn does not close. Going around a lone quark, the phase comes back changed, and that mismatch the medium cannot undo at any point: it has to hold it along a sheet that runs from the quark to the rest.

Every new stretch of separation lengthens the sheet and is one more stretch of mismatch to pay for, so pulling on the quark costs more the further it is taken, in proportion to the distance, and it is never seen on its own. Only the combinations in which the turns close exist on their own: three quarks, adding up to a whole turn, and the pair of a quark with an antiquark, in which the two cancel. Neither a lone quark nor a pair of quarks closes, and neither has ever been seen. That is color confinement, and here it follows from the shape of the medium.

Closing is what allows something to exist on its own, which is not the same as lasting. The

quark-antiquark pair closes, and that is why it exists on its own: those are the mesons, which accelerators produce by the million and which live a minute fraction of a second. The proton, besides closing, lasts. Its number of matter —the baryon number— is a whole number that no deformation of the medium changes, and its three whirls are linked so that none of them can leave on its own: that is why nobody has seen a proton decay.

Light and the forces: the phase that circulates

[DERIVED]

The circulation of the phase around the rings of the lattice, written as a field, is electromagnetism; with a richer internal spin, the nuclear forces.

The variable of the sector is the bond phase $a_{nm} = -a_{mn}$, one per bond. The primitive cell of the diamond has two sites and four bonds, and the bond space splits into two halves of dimension two: what the sites produce —the mode θ_- , gapped, and θ_+ , longitudinal— and the *cycles*, which are transverse. The photon's two polarizations are those two cycles. The minimal closed loop of the lattice is the nearest-neighbor hexagon (twelve per site); on it the circulation $\oint a$ is exactly gauge invariant, and the circulation operator gives two degenerate, isotropic eigenvalues, proportional to k^2 , in the two transverse directions. Written as a field, its energy is:

$$E_{\text{mag}} = \frac{8}{9} F_{\mu\nu} F^{\mu\nu}, \quad F_{\mu\nu} = \partial_\mu a_\nu - \partial_\nu a_\mu,$$

where a_μ is the phase angle accumulated in each direction. What that pair of formulas says is that the electromagnetic field, $F_{\mu\nu}$, is nothing other than the difference between how much the phase turns on going around a loop one way and how much it turns on going around it the other; and that the energy it stores goes with the square of that difference, with the 8/9 in front, which comes from summing the oriented areas of the six faces opened by the pairs of bonds of a node. From this follow the Bianchi identities —the two homogeneous Maxwell equations, which hold by themselves as soon as the field is written as the circulation of a phase— and, via Euler-Lagrange, the other two in free space: $\square \mathbf{a}_\perp = 0$, with $\omega = ck$ for both polarizations. Free-field Maxwell is [DERIVED]; with the topological charge of the knots as source, [SLD].

If the internal group does not commute, the same construction adds the term $i[A_\mu, A_\nu]$, where the capital A is that same accumulated angle when what is carried is the pair of phases of the cell, the doublet of sites A and B, and the structure of Yang-Mills appears. The groups come out as the symmetries of the objects the medium carries: $SU(2) \times U(1)$ those of the doublet, and $SU(3)$ those of the triplet of whirls of the baryon. That this doublet is the one of the observed weak sector is the hypothesis the program declares under its own name, **H-doblete**.

And light travels at c without having to impose it: the phase disturbance propagates at the maximum rate of change of the medium. The speed of light and the limiting speed are the same quantity measured two ways. The photon's channel has no gap: it is the Goldstone mode of the phase symmetry.

And with the group that does not commute, the same construction leaves a topological obstruction besides: it is the form in which color confinement is written into the lattice.

The check. The 8/9 is not chosen: it comes from summing circulations over the faces of the lattice, and were that sum to give a different number there would be nowhere to readjust it, because the same coefficient fixes the energy of the field and drags all of electromagnetism with it. The isotropy is not assumed: it is checked, and lengthening a single bond breaks it. And the photon's lack of a gap is exact because the symmetry imposes it; experiment bounds it below 10^{-54} kilograms.

What this changes. Maxwell and Yang-Mills are obtained without postulating any electromagnetic field. *Gauge* theories are the ones that describe a force from an internal symmetry: with rotations that commute, Maxwell; with rotations that do not, Yang-Mills. That the two come out of the same geometric construction, and that in the case of electromagnetism the coefficient and the two polarizations come out derived as well, is what allows treating them as branches of the same trunk rather than independent chapters.

Why electric charge comes in whole units. A knot of the medium does not come undone by pulling on it, just as a knot tied in a closed loop of rope does not come out without cutting the rope. And the electric charge of a particle turns out to be, quite simply, *the number of times*

the phase wraps around the knot. A count of turns.

A turn of the phase around a knot has to close, because the phase at each point is a single one: on going around the knot and coming back, the hand has to coincide with itself, and that only happens after a whole number of turns. Whatever moves about freely can only carry a whole number of turns. That is why charge comes in exact units and not in any old value —there is no other way to wind something—. Quarks carry thirds, and that is exactly why they do not move about freely: they exist only inside the combinations that close, where the thirds add up to a whole.

The neutrality of matter: two opposite turns that add to zero. Ordinary matter is electrically neutral: the positive charge of the proton cancels the negative charge of the electron exactly. Experiments have checked that cancellation to one part in 10^{21} —had there been a mismatch of one part in a thousand million million million, it would already have shown up—. In the Standard Model of particle physics this is accepted as a datum: the charges are assigned so that they cancel, and the theory does not say why they take the values they take. Here it does: if charge is a number of turns, the proton carries one turn and the electron that same turn in the opposite sense. One turn minus one turn is zero, and between two whole numbers there is no room for a difference of one part in a thousand million million million.

And there is a second reason, the one that closes the argument: the medium cannot wind a single turn on its own. Undoing a turn would mean taking the compression down to zero at some point, and the lower wall —Klauder’s— prevents it. Turns only appear and disappear two at a time, one in each sense, so the total count stays what it was: out of a medium that began with no charge, only neutral matter can come.

Chemistry comes from here too. There is a theorem, the spin-statistics theorem, which Wolfgang Pauli proved in 1940: anything that spins with spin one-half is forced to behave in a very particular way, and two such objects can never occupy the same state. That is the exclusion principle, which Pauli himself had stated in 1925. In ordinary physics the theorem rests on three assumptions —that the laws do not change with motion, that no influence travels faster than light and that energy has a floor—, and in the Pleno all three are properties of the medium. The electron has spin one-half —it is what the Dirac construction of the quantum world delivers—, and that is why the principle holds for it.

The proton and the neutron arrive at the same thing through another door, that of topology: the branch of mathematics that studies what does not change when something is stretched or bent without being cut, like a knot, which is still the same knot however much the rope is twisted. Their number of matter is a link between two lines of the medium, and there is a theorem —that of David Finkelstein and Julio Rubinstein, of 1968, in the form Frank Wilczek and Anthony Zee gave it in 1983 for this kind of link— that forces every knot with that number odd to behave in the same way.

And it is the principle that makes the electrons of an atom, instead of all piling into the lowest level, stack in successive shells. The shells are what give each element its chemical character, and their order is exactly the order of the periodic table. All of chemistry —why sodium reacts furiously and neon not at all, why carbon forms chains and with them life— is understood from that principle. In quantum mechanics it is added as a postulate. Here it is a consequence of how the medium is made.

And why the quarks are three. The proton carries one turn of matter, and that turn splits into three whirls linked in the manner of Borromean rings —three rings interlaced so that they hold one another and, if any one is removed, the other two come apart—. That there are three is not chosen: the crystal fixes it. The symmetry of each node of the diamond, that of the tetrahedron, sorts the ways of turning into families, and the one this turning belongs to has

exactly three members.

That winding of matter splits into three equal parts, a third for each whirl. But electric charge is a different count over those same three whirls, and there the sharing does not have to be even: the only demand is that the set close.

Since the unit of that ladder is the third, the closing condition is read off the numerators, and it works like a clock that had only three hours: the three whole numbers have to add up to a multiple of three. It is the rule Blomquist, Syrwid and Babaev proved in 2021 for trios of linked whirls of this kind. Two thirds, two thirds and minus one third —the whole numbers 2, 2 and -1 — add up to three, they close, and they give a total charge of one: that is the proton. Two thirds, minus one third and minus one third add up to zero, they close as well, and they give a total charge of zero: that is the neutron.

They are exactly the charges physicists measure in quarks, and also the asymmetry they observe, two alike and one different, which here comes from the three whirls not being interchangeable.

And the knot has measurements, not only a shape. The proton and the Δ particle —a resonance that accelerators produce and that decays at once— are the same trio in two states of spin, and the difference of their masses is the energy of making it spin faster. With the measured size of the proton, the computation gives two hundred and sixty-four megaelectronvolts (264) against the two hundred and ninety-three measured (293): ninety percent (90%), with nothing fitted.

Matter: knots, whole charge, and three quarks

[DERIVED]/[SLD]

Counting the turns and the links of the knots of the medium gives whole charge, chemistry and the three quarks.

The proton and the neutron are solitons of class M: configurations of the cell doublet, $\Phi = (\varphi_A, \varphi_B)$, whose baryon number B is the *Hopf invariant* of that doublet —the linking of two lines of the field, as the Gudnason-Nitta theorem establishes—. It is a whole number no deformation changes, and it exists because the medium does not vanish at any point: without that condition, the invariant would not be defined. It is not an $SU(2)$ skyrmion, the object Tony Skyrme proposed in 1961: the medium does not admit that target, and what links are the two components of the doublet. What keeps the knot from collapsing —Derrick's theorem would say it collapses— is Faddeev's quartic term, which turns out to be the same Maxwell term with its 8/9: the soliton of matter and the photon rest on the same term of the medium.

Electric charge is the number of turns. Charge is the *winding* —the whole turns of the phase around the defect—: the single-valuedness of the phase at each point forces $\oint d\theta \in 2\pi\mathbb{Z}$, and a whole number admits no intermediate values. The electron is a winding -1 defect, anchored in a gap of the lattice; the proton adds up to $+1$ over its three whirls. From this follow two exactitudes that standard physics takes as given without explaining them: that every free charge is an exact multiple of the electron's, and that matter is neutral, confirmed by experiment to one part in 10^{21} . The total winding is conserved by the topology of the phase, and Klauder's wall, which keeps $S > 0$, prevents a turn from being undone.

Chemistry comes from here too. The two fermions of matter are fermions by two routes. The electron, through the covariant Dirac construction: a Lorentz spinor of spin one-half and the spin-statistics theorem, with its three premises derived from the medium. The baryons, because their Hopf invariant is odd: the Finkelstein-Rubinstein criterion, in the Wilczek-Zee form, gives the phase $(-1)^B$ on turning them through a full revolution. There is the Pauli exclusion principle, and with it the periodic table.

And the three quarks. The number three is the dimension of the triplet of the symmetry group of the diamond node (the binary tetrahedral group, $2T$). The proton's $B = 1$ turn is read as three Borromean-linked vortices, each with a third of the baryon number, and the Blomquist-Syrwid-Babaev congruence, $\sum_j q_j \equiv 0 \pmod{3}$ on the numerators, returns the observed charges, in thirds: $(2, 2, -1)$ for the proton, which add up to one, and $(2, -1, -1)$ for the neutron, which add up to zero.

[SLD]

And the trio spins. The nucleon and the Δ are the states $J = \frac{1}{2}$ and $J = \frac{3}{2}$ of the same rotor, and the separation of their masses is

$$\Delta m = \frac{9(\hbar c)^2}{2m_p c^2 R_p^2} \approx 264 \text{ MeV},$$

with the measured proton radius, $R_p = 0.8408 \text{ fm}$, against 293 MeV observed: 90%. The Δ comes out at 1202 MeV against 1232. The formula is [\[DERIVED\]](#); the comparison, [\[SLD\]](#).

What this changes. That matter comes in whole units, that charge is quantized, that quarks are three and not two or five, and that an exclusion principle exists, are facts the Standard Model describes precisely but does not explain: it takes them as given structure. Here they are consequences of the medium being knotted, and the same rotor, with the measured size of the proton, gives the separation between the nucleon and the Δ to ninety percent (90%).

All of this, with *a single substance*. There is the Pleno, and its different ways of compressing, spinning, undulating, and flowing.

14. The dark sector: what the other 95% of the universe is made of

Of every hundred units of the universe's content, ninety-five (95) are of two kinds nobody has identified: an invisible mass that holds the galaxies together, and something to which ordinary physics attributes the acceleration of the expansion and which it writes into its equations without knowing what it is. In the Pleno the two are the same medium in two different states.

Dark matter, and why it is dark. That invisible mass that holds galaxies together, and that dozens of experiments have been hunting for decades without ever seeing, is another family of configurations of the same medium. Ordinary particles are knots whose phase winds around them, and from that winding electric charge and light are born. Dark matter is a smoother lump: it weighs, because it deforms the medium, and its phase spins, but it spins all at once, in step, without winding around the lump. What it lacks is precisely the winding, which is the circulation that produces electromagnetism.

That is why it is dark: it is not that it “barely interacts” by chance, it is that it does not have the mechanism that generates light, so it cannot shine or reflect anything, nor leave in a detector any trace but its weight. It is not an exotic particle of another nature: it is the same Pleno, organized without that winding. Ordinary and dark matter are first cousins: one knotted and luminous, the other smooth and mute.

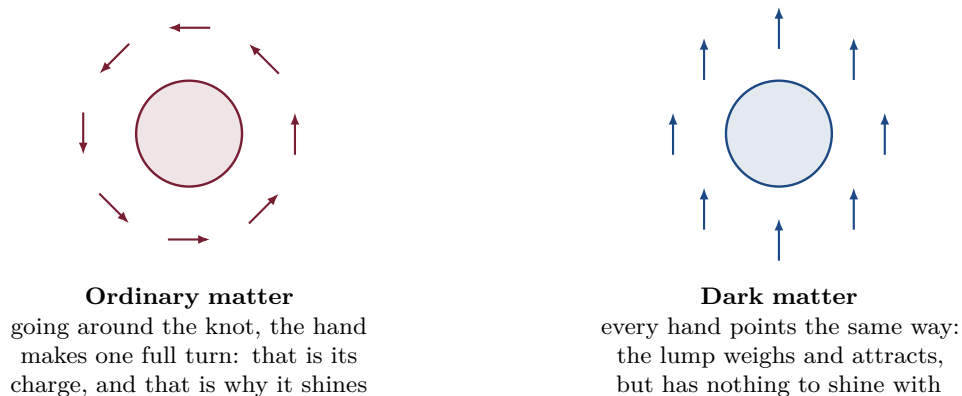


Figure 10: The two ways of clumping the medium admits. **On the left**, ordinary matter: going around the knot, the hand of the phase makes one full turn, and that count of turns is its electric charge. **On the right**, dark matter: the hands all turn at once, without winding around anything. It weighs just the same; what it lacks is anything to shine with.

And the proportion between the two can be computed. Dark matter, with no knot to pin it to the lattice, rounds itself off freely, and its boundary is a sphere. Ordinary matter, being knotted, stays pinned to the four bonds of its cell, and its boundary is the tetrahedron those bonds form, inscribed in that same sphere. How much of each class forms goes with the area of its boundary.

And that the weight should go with the area of the boundary, and not with the volume, has its reason. Inside the lump the medium is pressed against its upper wall, the Gent wall, and there it can barely tremble any more: the wall smothers the fluctuations of the interior. All that is left free is the surface. Counting the ways the lump can vibrate is then counting the modes of its boundary, and that number goes with the area.

The proportion of dark to ordinary matter is therefore the area of the sphere divided by that of the tetrahedron. And to that ratio one must add a factor of two contributed by the spin of ordinary matter: it takes two full turns to bring an electron back to where it started, so read as an observable rotation it counts for half. The ratio turns out to be a pure number, $\sqrt{3}\pi$, that is 5.44, and what the satellites measure is 5.375 ± 0.077 : it lands inside the error bars, with not a single parameter adjusted. In the standard cosmological model, how much dark matter there is per gram of ordinary matter is a number that is measured and accepted without anyone knowing why it takes the value it takes.

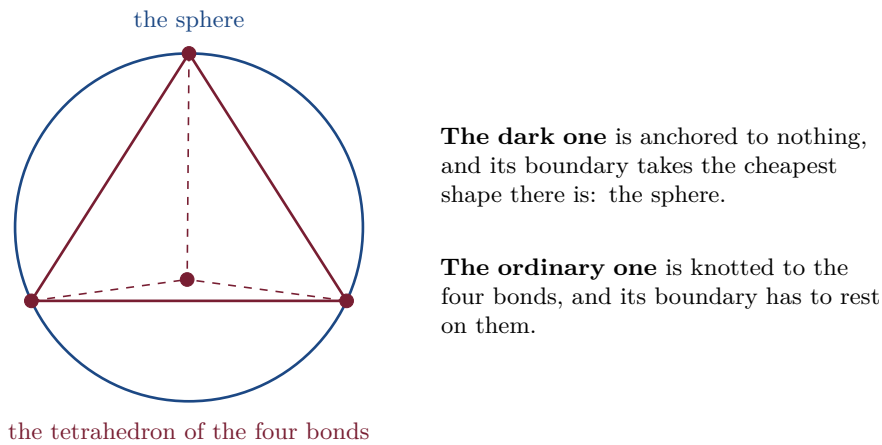


Figure 11: Where the proportion between the two kinds of matter comes from. The dark one, with no knot to anchor it, rounds off, and its boundary is the sphere; the ordinary one is held to the four bonds of its cell, and its boundary is the tetrahedron those bonds form, inscribed in that same sphere. The area of the one divided by that of the other, with the factor two the spin contributes, is $\sqrt{3}\pi$.

The share of the dark sector: a ratio of areas

[DERIVED]

The ratio between the two classes of matter is the quotient of two areas.

The two classes of matter differ in a single thing: whether the medium is caught on the bonds of the crystal or not. The knotted kind has its phase wound, and its number of turns—a linking, what mathematics calls the Hopf invariant, after Heinz Hopf—is conserved by topology; the smooth kind are the *Q-balls* Sidney Coleman described in 1985, which do not wind and which the conserved charge of their spin holds together. And that difference decides what shape the boundary of each takes.

Dark matter carries no winding to anchor it to the lattice. Its boundary is left free, and a free boundary takes the cheapest shape there is for enclosing a volume: the sphere. That is the isoperimetric theorem, and it is the reason a soap bubble comes out round instead of square. Ordinary matter does knot itself, and the winding catches it on the four bonds of each node, so that its boundary has to rest on them: the shape four such points dictate is the *coordination tetrahedron*, inscribed in that same sphere. Neither of the two shapes is chosen; they are the only two the medium offers.

What each class weighs goes with the area of its boundary, so the proportion between the two is the proportion between those two areas. And a factor of 2 is missing, which is not chosen either.

Ordinary matter is fermionic, and a fermionic object lives in a space of turns that goes around twice for every turn of the observable world: it is what separates the electron, which needs two full turns to return to its initial state, from a spinning top, which returns with one. On counting the weight of ordinary matter in what an observer can see, that double cover is projected down and its weight is reduced to exactly half—the exact ratio is given by the Peter-Weyl theorem—. Dark matter does not suffer that reduction, because it is not fermionic.

That is where the two comes from, and it comes from the least expected place: the half is in the *denominator* of the ratio, with ordinary matter, and dividing by one half is multiplying by two. That is why the proportion doubles:

$$\frac{\Omega_{DM}}{\Omega_b} = \frac{2A_{\text{sphere}}}{A_{\text{tetrahedron}}} = \frac{2(4\pi R^2)}{(8\sqrt{3}/3)R^2} = \sqrt{3}\pi \approx 5.4414$$

where each Ω is the share of the universe's content that falls to that class: Ω_{DM} to the dark and Ω_b to the ordinary. The measurement by the Planck satellite (2018) gives 5.375 ± 0.077 . That is agreement at **0.86 σ** with *zero* free parameters. The letter σ (read “sigma”) is the unit in which a discrepancy is measured: one sigma is the typical error margin of that measurement, so 0.86 means the difference between what is computed and what is measured is smaller than the instrument's own error.

The check. The comparison is made against densities read directly off the heights of the peaks of the cosmic microwave background—the oldest light in the universe, whose ripples say how much matter of each class there was—, and not against numbers that are already the output of a previous fit.

And comparing two densities has an advantage over measuring just one. To turn what the sky shows into a density one has to know the rate at which the universe expands, and that rate is not known with full exactness: each of the two densities therefore drags a margin of doubt with it. But it is the same margin in both, because the rate enters them in the same way. On dividing one by the other, that shared doubt disappears from the result, and the ratio that remains is firmer than either of the two numbers on its own.

What this changes. How much dark matter there is per unit of ordinary matter is today a number that is measured and written down, and no theory says why it takes that value. And the two shapes were not picked to make the sum come out: they are the only two the medium offers, and the tetrahedron is the same one of the four bonds from which the floor and the ceiling already came. The proportion of the cosmos is written in the shape of the crystal, there is no knob at all to turn, and even so the number falls within the margin of what is measured.

Matter, radiation and the background are three states of the same substance, and each has its **equation of state**, which physics sums up in a number called w : the pressure of that state divided by its own energy density. It is a number without units, because it measures each state against itself. And from that ratio follows, by plain conservation of energy, what happens to its density when the universe stretches. The accounting is that of a piston. As the volume grows, what is inside it is spread over more room, and that already dilutes it; if it also pushes, it spends energy pushing a wall that is moving away. Pressure is then what says how much more is lost: nothing if it does not push, something if it does, and if instead of pushing it pulls, the energy is not lost but replenished.

Matter is knotted lumps, and a lump does not push: its pressure is zero and its w is zero, so as the medium stretches the lumps are merely left further apart and their density falls with the volume. The same holds for the ordinary and for the dark.

Radiation is waves, and a wave does push, with a third of its density. It pushes in the direction it travels, and waves travel in the three directions alike, so on any given wall only one in three bears down: its w is one third. And its density falls faster, because besides spreading apart each wave is lengthened, and in lengthening loses energy: the energy of a wave goes with its frequency,

and stretching is dropping in frequency.

Dark energy —ordinary physics attributes the acceleration of the expansion to it and adds it to its equations without knowing what it is— is the part of the Pleno itself that moves in unison: the condensate of its phase, at rest at the bottom of the well. Even where there are no particles or waves, that part is present everywhere, like the still water of an ocean on which all the waves rise. And what stretches when the universe expands is not a container holding the Pleno: it is the Pleno itself distending.

It has to be told apart from the floor itself. The bottom of the well has an energy of its own, of the order of the density of the medium, and that energy is the **curtain**: the zero from which everything else is counted, the permanent background that stands behind the stage and is no part of the scene. The curtain does not gravitate. If it did, dark energy would be a hundred and twenty-three (123) orders of magnitude larger than what is observed, and that is, in its usual form, the cosmological constant problem. What gravitates is what the medium holds today above that floor, and dark energy is the part of that excess that still moves in unison.

It sits, then, at rest at the bottom of the well, and there the piston accounting changes sign. Pressure is what a medium hands over when it is allowed to take up a little more room: a gas hands over energy as it expands, and that is why it pushes. The medium at rest does the opposite. Opening new volume in it hands over nothing: it costs, and it costs in exact proportion to the volume opened, because every new portion arrives with the same density of dark energy already in it. A pressure that is a cost instead of a handing-over is that same density with the sign reversed, so its w , which divides pressure by density, is -1 .

Put into the piston accounting, that value says the density of dark energy stays as it is however much the volume grows: stretching the medium does not change it. The Pleno delivers it exactly, and with nothing fitted. And that cost is the same from wherever it is looked at: a medium at rest has no direction and no velocity to single it out, so there is no observer for whom the accounting comes out different.

From that follows what is observed today. Since matter thins out and dark energy does not, the fraction dark energy represents in the balance of the universe keeps growing. **Its weight grows, not its density**: it is everything else that is dwindling. When the universe was half its present size, dark energy weighed a little over a fifth of the total (0.2152); when it was a third, less than a thirteenth (0.0751); today it weighs almost seven tenths (0.6869). And what grows is that weight, not the part of the medium that moves in unison: that fraction does not rise, it relaxes, and it has come down from when it was set (0.7185) to today (0.6869).

Where the Pleno parts from the cosmological constant —the fixed energy of space that Einstein introduced in 1917 and that the standard cosmological model takes up again: since it does not thin out, it accelerates the expansion forever— is in the destiny. In the Pleno what moves the background is not the energy but the slope of the well, and at the bottom of the well that slope is zero: an energy that exerts no force produces no motion. Dark energy does not thin out while the medium finishes relaxing, and even so the expansion rate tends to zero: that density runs out when the relaxation ends, and the curtain, which is still there, moves nothing. The floor stays where it is; what disappears is the slope that was left to descend.

The densities one by one, and a background that does not thin out[DERIVED]/[CALIBRATED]

The four densities come from the proportion between the two kinds of matter and from a single positional reading: the hour the cosmic clock shows today.

The ratio of areas fixes the *proportion*, not the figures. The individual values further inherit a *positional reading*: where the medium stands today along its path, like the hour a clock shows —the machinery is theory; the hour is read—. In this sector that reading is the condensate fraction f_c , the

part of the medium that today moves in unison. That part is dark energy, and the rest, trapped in knots and lumps, is matter: hence $\Omega_{DE} = f_c$ and $\Omega_m = 1 - f_c$, and matter in turn splits between dark and ordinary in the proportion $\sqrt{3}\pi$. It is a single reading for the whole sector: it is taken once, and the four densities come from it.

And not even that number comes whole from the world, because part of it is computed. It can be split into two factors that multiply: one that comes from the geometry of the crystal and is derived, and another that is the reading proper. Only the second comes from the world:

$$f_c = \underbrace{0.2401}_{\text{geometry}} \times \underbrace{2.8604}_{\text{state}} = 0.6869,$$

where the first factor is how much of its maximum capacity the medium at rest occupies, the square of its floor divided by that of its ceiling: pure geometry. The ceiling comes from comparing the diamond crystal with the tightest packing of spheres there is, that of the Kepler conjecture, which Thomas Hales proved. The second compares against that floor the occupancy the condensate still holds today, and it is what is taken from the world. With that, the whole block of densities falls out:

Quantity	PIU- Ψ	Planck 2018	Agreement
$\Omega_{DE} = f_c$	0.6869	0.6847 ± 0.0073	0.30σ
$\Omega_m = 1 - f_c$	0.3131	0.3153 ± 0.0073	the same
Ω_{DM} (dark)	0.2645	0.265 ± 0.007	0.07σ
Ω_b (ordinary)	0.0486	0.0493 ± 0.0006	1.2σ

The first two rows are a single comparison, not two hits: the model the data are read with assumes a flat universe, so the two fractions add up to one, and getting one right is getting the other right.

Dark energy, moreover, is the phase condensate at rest at the bottom of the well, and hence its pressure is the same in every direction and for any observer—in the writing of relativity, its energy tensor is proportional to the metric—: its w is exactly -1 , with nothing left over.

The check. And were anything left over in that accounting, it could only be left over on one side: the kinetic term cannot be negative, and that forces $w + 1 \geq 0$. Departing from -1 requires the medium, besides sitting at the floor, to be moving a little, and moving always adds energy and a pressure of the ordinary sign. That can only raise w , never lower it. The theory thereby vetoes the “phantom” region where w would be below -1 . And the signal of varying dark energy the DESI analyses believe they see points to the opposite side, the one a medium at rest mimics when it is looked at with a template built to catch change—the parametrization of Chevallier, Polarski and Linder—.

What this changes. The dark sector is ninety-five percent (95%) of the content of the universe, and in the standard cosmological model those densities come from free parameters fitted to the data, with no reason underneath. Here all four stop being parameters and become consequences. In this sector, the only thing taken from the world is one reading—at what point of its path the medium stands today—and of that reading one part is not taken either: it is derived from the geometry of the crystal. All four fall within one and a quarter sigma (1.2σ) of what the Planck satellite measures, and dark energy and total matter, which are a single comparison, within three tenths of a sigma (0.30σ).

15. The heat of the medium itself

What is temperature, if all that exists is a single substance? In ordinary physics, heat is handled with its own apparatus—thermodynamics and statistical mechanics—, with its own rules about how energy is shared out among many particles. Here that loan is not available: if the Pleno is all there is, heat has to be something that happens to the Pleno, and its laws have to come out of counting it.

And they do. Temperature, on this reading, is disorder of the spin: when the orientations of all the cells are in step, the medium is cold—that is the condensate, which is dark energy—; when each cell spins on its own, out of agreement with its neighbors, the medium is hot. Temperature and disagreement among the spins are, here, one and the same.

And since the medium has a compression ceiling, it also has a maximum temperature: the point where the gas of vibrations —heat itself, which here is waves of the medium— reaches the medium’s ceiling of density, the same one as its upper wall, and no more heat fits. Heating is filling the medium with vibrations, and vibrations weigh: the more there are, the tighter the medium that carries them. When the heat approaches that ceiling there is no longer anywhere to put the next vibration, and there the scale of temperatures ends. And that point is computed. The vibrations the medium admits are those of its crystal, each family on its own band of frequencies, and counting them all the ceiling falls at a little over two and a third times the Planck temperature ($2.3545 T_P$), the scale of temperature formed with the same measures of the grain and named after Max Planck.

Imagine sharing identical coins among several piggy banks. Since the coins are alike, two sharings differ not by which coin went where, but only by how many coins ended up in each bank; and some sharings can come about in a great many ways while others can hardly come about at all. Equilibrium is the sharing that can come about in the most ways.

The piggy banks, in the Pleno, are its modes. A mode is one of the independent ways the medium has of vibrating: an undulation with its own wavelength and its own frequency, which can carry more or less vibration without getting in the way of the others. It is the business of a guitar string, where the fundamental note and its harmonics fit and nothing else. The vibrations of the medium are shared among its modes in exactly that way, and it is enough to do that count, importing no law of heat from outside, for Bose-Einstein statistics to come out, which describes how photons and the whole family of bosons share out the energy, the particles that can pile up without limit in a single state.

That rule was written by Satyendra Nath Bose and Albert Einstein in 1924, and it says how many identical particles are to be expected in each state when none gets in the way of the others. With it we predict the exact color of the light a hot body emits —it is the law Max Planck found in 1900, and here it comes out of the same count— and the spectrum of the cosmic microwave background, and with it are designed the laser and the traps for ultracold atoms. In ordinary physics it is deduced by assuming that the particles are indistinguishable and that all configurations are equally likely: the counting is put in, not derived.

And integrating that occupation over the modes gives the Stefan-Boltzmann law, the one that says how much a hot body radiates —twice as hot, sixteen (16) times as bright—, with its exact coefficient.

Josef Stefan measured it in 1879 and Ludwig Boltzmann deduced it in 1884. It is the one that lets you take something’s temperature without touching it: the ear thermometer, the infrared camera, the temperature of a star from its brightness, and the energy balance with which the Earth’s climate is computed. Its coefficient, however, carries inside Planck’s constant and Boltzmann’s, which in today’s physics are measured numbers: the law is deduced, but the number in front of it is inherited. The thermodynamics of the Pleno is not borrowed from another theory: it is deduced from counting its own configurations.

Bose-Einstein and Stefan-Boltzmann, by counting

[DERIVED]

The two statistics of the world and the law of glow come out of counting configurations of the medium itself.

F1 is expanded to second order about rest, and each phase mode becomes a harmonic oscillator, an ideal spring that vibrates with its frequency ω_k fixed by the medium. One then counts in how many ways *indistinguishable* vibrations can be shared among those oscillators. It is pure combinatorics, that of the piggy banks, and it gives the *entropy* per mode —entropy is, quite simply, in how many

different ways one and the same sharing can come about: the more ways, the greater it is—:

$$\sigma(n)/k_B = (1+n) \ln(1+n) - n \ln n.$$

What that expression says is in how many ways one can have n vibrations in a mode, counted on a logarithmic scale—the $\ln$ is the logarithm, the way of handling counts that run away, and k_B is Boltzmann's constant, the number that translates temperature into energy—. And equilibrium is demanded using the native definition of temperature, $1/T = dS/dE$, where S is here the entropy—not the modulus of the medium—: the inverse of the temperature says how much that count of ways grows when a little energy is added. That forces the mean occupation:

$$\langle n \rangle = \frac{1}{e^x - 1}, \quad x = \frac{\hbar\omega}{k_B T}$$

which is Bose-Einstein statistics. And that there is no occupation ceiling does not have to be assumed: it is seen in what kind of thing the phase mode is. It is an undulation of the angle, and another undulation can always be added on top of it in the same mode, as two waves add at the same spot of the sea. A knot, by contrast, is either there or not: where there is one, no other fits. Hence the two families count differently—the phase mode is a Goldstone boson, with its angular momentum in whole multiples of $\hbar$ —. The same count, made over configurations that *do* have an occupation ceiling, delivers the other statistics of physics, **Fermi-Dirac**—Enrico Fermi and Paul Dirac, 1926—, with which the electrons of metals and semiconductors are described, and the one that sustains the Chandrasekhar limit. And the ceiling is not assumed either. For the electron it comes with its own equation, Dirac's, which already came out of the medium: from it follow at once its two senses of spin and the fact that where there is one no other fits. For the knots of matter it comes with the criterion of Finkelstein and Rubinstein—in the form Wilczek and Zee gave it for linked knots—, the same one behind the exclusion principle, applied to those carrying an odd number of turns.

Integrating that occupation over all modes gives the entropy per unit volume:

$$\frac{s}{k_B} = \frac{g_*}{2\pi^2} \int_0^\infty k^2 \sigma_k dk = \frac{2\pi^2}{45} g_* \left(\frac{k_B T}{\hbar c} \right)^3,$$

The sign $\int$ is a sum: it adds the contribution of all the modes, one after another. And the g_* counts the independent variants each wave has—two for light, one per polarization—. From that entropy comes the energy density: in a radiation gas the two are tied together, and the energy is three quarters of the product of the entropy and the temperature. Since the entropy grows with the cube of the temperature, the energy grows with its fourth power. That is the Stefan-Boltzmann law, with its coefficient and with no fitting. In the numerical check, the occupancy is obtained by solving the equation by bisection, *without* using the deduced Bose-Einstein formula, and the integration is then done blind. The result, 0.877298168985721 for two polarizations, is the entropy coefficient of the formula above, $2\pi^2 g_*/45$ with $g_* = 2$, and agrees with the closed form to all fifteen (15) figures of double precision.

The check. Had the combinatorics returned a different mean occupancy, there would have been nowhere to correct it. And an error in the counting would have separated the two numbers at the first figure, not the sixteenth.

What this changes. The statistics of photons and the law that says how brightly a star shines—the latter with its exact coefficient— come from counting configurations of the same substance that gives gravity and charge. A whole branch of physics believed to be independent turns out to be a consequence of the same Lagrangian.

And from that same count comes the other statistics of the world. Photons pile up without limit in a single state; electrons do not: where there is already one, no other fits. That difference, which looks like a caprice of nature, turns out here to be a single thing—whether the configuration is knotted or not—and the electrons' version is called Fermi-Dirac statistics. It is what decides, inside a star, how much weight its electrons can bear.

The same computation yields a *window* for the friction of fluids. Every fluid has internal friction: it is what in the kitchen is called thickness, a lot of it in honey and little in water. Physics conjectures, without having proved it, that no fluid can go below a certain minimum. That minimum is not one of friction plain and simple, because honey has a lot of it and water little and neither is anywhere near any limit: what is bounded is friction compared with the fluid's own disorder, with its entropy —what it costs to pass a shove from one layer to the next, for each way it has of being jumbled—. Every fluid measured respects it.

In the Pleno that minimum has to exist: the medium is always full, and no mode can isolate itself from its neighbors to stop rubbing. What the Pleno adds is the other end, a ceiling. The more it costs the medium to pass a shove from one layer to the next, the longer it takes to pass it, and no process of the medium can be slower than its own thermal clock —the one its temperature sets for it, which runs faster the hotter the medium is—.

Between the two bounds lies a narrow band, from one to $4\pi/5 = 2.5133$ times the universal minimum conjectured by Pavel Kovtun, Dam Thanh Son and Andrei Starinets in 2005. And inside it falls the quark-gluon plasma that accelerators produce —the soup protons dissolve into when they are pounded at millions of degrees—, the most perfect fluid ever measured. The Pleno itself falls inside too: with the relaxation time its bending term sets, its friction sits thirty-two percent above the minimum (1.3232 times). Ultracold atomic gases, twenty-one (21) orders of magnitude colder, sit at twice that ceiling, some five times the minimum, and in the direction the medium itself dictates: their vibrations have a minimum energy threshold, and a medium like that relaxes more slowly.

16. The stars: the mass at which a life ends

Gravity, the quantum and heat come together in something telescopes see every night: the death of a star.

When a star like the Sun runs out of fuel it has nothing left to push outward with, and its own weight crushes it. The collapse does not go on forever: it stops, and what stops it are its electrons. By Wolfgang Pauli's exclusion principle —the same one that orders the periodic table— two electrons cannot occupy the same state, so squeezing them costs more and more, and that refusal to share a place is what holds the star up. The places fill from the bottom up, and squeezing the star leaves fewer slow places free: the electron that does not fit where there is already another has to make do with a faster one. Squeezing forces it to run, and a swarm of electrons forced to run pushes outward. The result is a *white dwarf*: an object the size of the Earth with the mass of the Sun, standing not because it is hot, but because its electrons refuse to stack.

But that refusal has a ceiling. If the star weighs too much, its electrons would have to move faster than light to keep holding it, and they cannot. Above a certain mass the white dwarf does not exist: the star keeps falling until it becomes a neutron star or a black hole. That threshold is the **Chandrasekhar limit**, which Subrahmanyan Chandrasekhar computed in 1931, and it is about 1.44 solar masses. It is one of the most tested numbers in astrophysics: it decides the fate of every star in the sky, and it is also what makes a certain class of supernova always explode with the same brightness —which is, in turn, what allowed the teams of Saul Perlmutter, Brian Schmidt and Adam Riess to discover in 1998 that the expansion of the universe is accelerating—.

In PIU- Ψ that number is computed in full, and the chain does not borrow stellar astrophysics: it builds it out of pieces of the medium itself. In come the $\hbar$ of the spin of a grain and the G of firmness; the Fermi-Dirac counting, which says how many electrons fit; and the speed ceiling of the dilatant medium, because the limit exists precisely because of it: with no ceiling on speed, the pressure of the electrons would grow without check and there would be *no* maximum mass.

The only thing that comes in from outside is what the star is made of. And that is not a constant

of the theory but a datum of the object: Newton's formula does not carry inside it the two masses one wants to weigh either; they have to be supplied. The result is 1.456 solar masses against the 1.44 known.

And that datum, put to work, turns into a prediction. The limiting mass goes as the inverse square of how many nucleons —the pieces of the nucleus: protons and neutrons— the star carries per electron —the same dependence as in the classical formula, here with each of its pieces drawn from the medium—: helium, carbon and oxygen carry two nucleons per electron, hydrogen one and iron a little over two. The ceiling therefore changes with composition: 5.83 solar masses if it were hydrogen, 1.456 for helium and for carbon-oxygen, 1.256 for iron. Populations of white dwarfs of different composition have to show those ceilings.

The mass at which a star dies

[DERIVED]

The Chandrasekhar limit comes out of the medium; the composition of the star enters as a datum of the object, not of the theory.

A white dwarf is held up by the pressure of its electrons pressed against one another, and above a certain mass that pressure no longer suffices:

$$M_{\text{Ch}} = \frac{\sqrt{3\pi}}{2} I_3 \frac{(\hbar c/G)^{3/2}}{(\mu_e m_u)^2} \approx 1.456 M_{\odot},$$

against the known value of about 1.44 solar masses. In the formula, $\hbar$ and G are the identities of the spin of a grain and of the firmness of the medium; $I_3 = 2.0182$ is the only numerical step in the whole computation, the integration of the star's profile; and $\mu_e m_u$ is the mass the star carries per electron. The profile is how the matter is laid out from the inside out, immensely dense at the center and ever thinner toward the surface; it is fixed by the way pressure grows with density, and I_3 comes from summing it layer by layer.

The chain has four links, and none of them admits a choice. The first counts how many electrons fit: each speed slot admits two, one for each sense of the electron's spin ($g = 2$), and from that comes the electron density. The second turns that swarm into pressure: since the electrons go in every direction alike, only a third of each shove presses against a given wall, and from that comes the factor one third. The third looks at the extreme case, with the electrons traveling almost at the speed of light, and then the pressure grows as the density to the power $4/3$. And the fourth is the surprising one. How much weight each layer of the star can hold up depends on how pressure grows with density; once that how is fixed —and the extreme case fixes it at $4/3$ —, it is settled layer by layer how much matter each one carries. That is exactly what the classical equation of the stellar interior —Lane-Emden with index three, after Jonathan Homer Lane and Robert Emden— takes for granted, and here it comes out on its own. Even the number in front, $\sqrt{3\pi}/2$, comes out derived.

The check. With $g = 1$ instead of $g = 2$, the mass shifts by a factor $\sqrt{2}$. And in the non-relativistic regime the index of the profile changes and there simply *is* no limiting mass: the ceiling exists because the computation requires the speed ceiling c , and for no other reason.

What this changes. Chandrasekhar got it right, and his formula still stands, with its complete coefficient: what changes is where its pieces come from. In the classical computation, the gravitational constant and the quantum one are taken as measured, and how matter is laid out inside the star is solved with an equation written separately. Here both constants are properties of the medium, and that layout does not have to be assumed: the computation itself decides it. Of the whole limit, the only thing still coming from observation is what the star is made of. And precisely for that reason composition stops being a datum and becomes a result with consequences: each class of white dwarf has its own ceiling, and the three are computed.

17. The large and the small: one material, seen from two distances

The wall of physics is this: the very large (gravity, the cosmos) and the very small (particles, the quantum) are described by two magnificent theories that do not fit each other, and in a century nobody has managed to unite them.

The program does not try to glue them, because it does not accept that they are two. Gravity comes out of the firmness of the medium; the quantum constant, out of the spin of its grain; and both come out of the same coefficient, evaluated from different sides. Gravity and the quantum are not, then, two worlds to reconcile by force, but the same material seen from two distances: close up one sees grain, spin and quantization; far away, curvature and cosmos. The gulf is not crossed. It dissolves, because there were never two shores.

From this follows the answer to the jam that ruined the earlier attempts. That jam arises from treating gravity as a fundamental force and trying to “quantize” it: to apply to it the rules of the quantum, in which every field trembles at every scale. When those tremors are added up down to ever smaller distances, without limit, the computations fill with infinities. In the other forces those infinities are gathered into a few measured constants; in gravity infinitely many would be needed, and the theory stops predicting anything.

Here that jam never forms, for two reasons. In the Pleno gravity is not fundamental—it emerges from the medium at large scales—and there is no need to quantize it, just as it occurs to nobody to “quantize” the waves of the sea knowing they are water. And the second reason is more material: infinities appear when infinitely fine structures are admitted, and this medium admits none. It has grain. Asking it what happens on a scale smaller than its cell is like asking what picture lies inside a pixel: the question has no content, and the material itself is what voids it.

The two modes of the medium, and the cutoff the grain sets

[DERIVED]

The medium admits two waves, and its grain keeps the computations from filling with infinities.

Disturbing the Pleno slightly gives two waves that do not mix: one in the modulus (how compressed it is) and one in the phase (which way it spins). That they do not get in each other’s way, at least to a first approximation, is what allows them to be followed separately.

The two formulas that follow use the two symbols any wave is described with: ω is its frequency—how many times per second it goes up and down—and k measures how tightly packed it goes, larger the shorter its wavelength.

The modulus mode is *massive*: its frequency never drops below a minimum—not even the longest wave comes free, and that is what having mass means—,

$$\omega^2 = c^2 k^2 + \omega_0^2, \quad \omega_0^2 = \frac{\xi c^2}{\ell_P^2}, \quad \xi = 19.69,$$

where ξ is the curvature of the well at its bottom, computed from the potential. That minimum mass is enormous—of the order of the grain’s—and the mode has been frozen since crystallization: no background dynamics remains that could move w from -1 , w being the ratio of the pressure of a content to its own energy density. Exciting that mode, even barely, costs an energy the size of the grain’s, and in today’s universe there is nothing able to pay it. Crystallization is the episode in which the medium ordered itself into a crystal.

The phase mode travels at the speed of light. On the lattice it carries a tiny correction, noticeable only at wavelengths near the grain:

$$\omega^2 = c^2 k^2 \left[1 - \frac{(k\ell_P)^2}{20} + \dots \right],$$

and the sign matters as much as the number: it is negative, so the texture of the medium slows the wave down and never speeds it up. A correction with the opposite sign would have put waves above c and broken the medium’s speed limit.

And there is not one correction for light and another for gravity, because both are undulations of the same phase. The undulation of the phase admits three forms, according to how many directions it takes to describe it: one with no direction at all; one with a single direction, which is the photon; and one that lengthens the medium along one direction while shortening it along the perpendicular, which is the gravitational wave. All three are undulations of the same phase, at neighboring levels, and they travel over the same bonds of the lattice, so they share exactly the speed

and exactly this correction. It is also the reason F1 needs no electromagnetic field added to it: what in ordinary physics is a separate field is here one of the levels of the phase the medium already has. At the shortest wavelengths —the *ultraviolet*, in physicists' jargon— the equation linking frequency to wavelength stops having a single answer and comes to have two: the usual wave, and a second response that would show only as the undulation came near the grain. That second one never becomes a real wave: it would have to be shorter than the grain, and in a medium with a fixed step there is no wave shorter than its step. That is where the cutoff comes from: the medium admits no curvature tighter than its grain, and that refusal is what keeps the computations from diverging.

And that same computation closes a question that stays open in other theories: whether probability is conserved. In theories with corrections of this kind —those of Tsung-Dao Lee and Gian Carlo Wick, from 1969—, the second response shows up as a strange state nobody knows what to do with, because it threatens to make probabilities stop adding up to one. In the Pleno the question never arises: the lattice sustains no frequencies above a ceiling ($\sqrt{12}c/\ell_P$), and the second response would begin higher up ($\sqrt{20}c/\ell_P$), outside what the medium can carry. On the lattice, the evolution of the medium conserves probability exactly, with no approximation whatever: it is what physicists call *unitarity*.

What this changes. The infinities that wreck attempts to quantize gravity are normally headed off with a cutoff introduced by hand and justified afterward. Here the material has grain, and that grain is in the axioms: that the computations do not fill with infinities at tiny distances is not a remedy applied afterward, it is a property of the substance.

A prediction follows from the medium having grain. A material with texture is not entirely transparent. Send light of high enough energy through it —so high that its wavelength approaches the size of the grain— and the light begins to notice the texture, and its speed departs a little from c . That happens to any material with grain.

What sets the Pleno apart is that its grain is not smooth: it is a crystal, with four bonds per cell pointing to the vertices of a tetrahedron. Those four vertices point at four alternating corners of a cube, along the four diagonals of its body, so that those four directions carry the axes of the cube with them. And a crystal has directions. The prediction, then, is that the effect should be somewhat larger in some directions of the sky and somewhat smaller in others, and that it should do so following the drawing of a cube: the same along its edges, different along the diagonals of its body. Between the direction in which the effect is largest and the one in which it is smallest there is an exact relation, seven thirds ($7/3$).

That is far from being measurable: the energy at which it would show is some seventy-five million times greater (7.5×10^7) than the best bound that exists today for a delay of this kind, the one that grows with the square of the energy. That bound was obtained in 2024 by the LHAASO observatory with the gamma-ray burst GRB 221009A, whose light traveled for billions of years and arrived without its most energetic photons having fallen behind. It is not a prediction for this decade. But it is defined in sign, in size and in direction.

And if the Pleno is a crystal, why does space look the same to us in every direction? Because the four bonds of the tetrahedron, averaged, behave exactly like a sphere for every wave much longer than the grain, which means every wave that can be measured; the directions of the crystal show only when the wave approaches its size. And a crystal with directions arising from laws that prefer none is the ordinary case: the equations of a magnet single out no direction, and the magnet, on cooling, ends up pointing in one.

The mark the grain leaves on the sky

[DERIVED]

The directional mark is a cubic pattern with an exact ratio, seven thirds, between its largest and its smallest value, and long waves see that crystal as a sphere.

The correction to the dispersion depends on direction as follows:

$$C(\hat{n}) = \frac{1}{20} - \frac{1}{18} K_4(\hat{n}),$$

where $\hat{n}$ is the direction of observation and K_4 measures how far that direction departs from the crystal's axes. The first term is the part that does not depend on direction; the second is the part that does, and its average over all directions is zero. And that formula is not a fit with two pieces chosen for convenience: with the symmetry of this crystal there are only two possible ways for the correction to depend on direction—the one that does not depend on it and the one that depends as K_4 —, so they are the only two pieces that fit.

Translated into what an observatory would measure—the energy at which the dispersion would start to show—, that energy at which the effect would show up is not the same everywhere: one has to go higher looking along an edge of the cube and lower looking along a diagonal of its body, with a factor of 1.5275 between the two extremes. That factor and the ratio 7/3 of the dispersion are the same datum said in two ways. The energy at which the dispersion shows up goes as the inverse of the square root of the correction, so squaring 1.5275 returns 2.33, which is 7/3. The part of the effect that does not depend on direction sits apart, and equals $2\sqrt{5}$ times the Planck energy, about 4.47. And photon and gravitational wave are delayed alike: the correction is set by the step from one bond to the next, and that step does not distinguish polarizations. For the same reason, the two polarizations of light travel side by side. That is not the usual case: a cubic crystal can split them—John Burnett and his colleagues measured it in calcium fluoride in 2001—, and that of the Pleno does not.

A crystal that long waves see as the same in every direction. A crystal has privileged directions; space, as far as has been measured, is isotropic, that is, the same wherever one looks. The two do not clash. The four bonds of the tetrahedron are so evenly spread that, for any computation depending on the square of the direction, averaging them gives exactly the same as averaging over the whole sphere—in mathematics that is called a spherical 2-design—. So every wave much longer than the grain sees a medium with no directions, and direction shows up only in a much smaller term, the one depending on the direction raised to the fourth, which is that of K_4 . And the mechanism by which a state with directions arises from laws that prefer none—that of the magnet on cooling—has a name in physics: *spontaneous* symmetry breaking. The equations of the Pleno single out no direction; what breaks the isotropy is the configuration that minimizes them.

If the crystal does not keep its orientation at large scales, only the part that does not depend on direction survives. If it keeps it, the pattern carries axes fixed in the sky; if not, averaging over orientations cancels the directional part exactly.

The check. There are microstructures that would cancel this trace entirely, but canceling it demands either another geometry of bonds or a second constant to tune with. The Pleno has neither: the axioms fix four equidistant bonds in a unique configuration, with not a single angle that can be turned.

What this changes. The theories that assume a minimum scale agree that it must leave some trace, and there they stop: each of them admits a range of possible traces, with a parameter fitted afterward. Here there is no parameter: the shape of the trace, its size and the direction in which it shows are all three fixed by the geometry of the crystal, and are computed, though there is as yet no measurement to confront them with.

18. Why this is science, and not a pretty tale

Beneath every image in this document there is a formal research program, subject to the same demands as any professional physics. The Pleno is described with **explicit mathematics**: it starts from precisely stated principles, derives its results the way one proves theorems, subjects every step to verification—recomputing the numbers with independent code that carries no preloaded result—and classifies every claim by its degree of certainty.

It explains laws we already knew to be true. The twenty-seven (27) laws, constants and facts on the list come out of its single equation. They were measured and confirmed, some of

them for centuries, but the chain of reasons ended in something accepted because it is measured: physics knew *that* they held and, at the bottom of it, not *why*. Here each one arrives with its own.

A validated law keeps its validity whatever the path that reaches it, and that part of the program rests on old, solid science, observed in thousands of experiments. **The contribution is the root:** a single origin for laws that today live in separate books.

The whole program fits, in fact, into thirteen (13) lines.

The program, in numbers

From a single statement —the universe is energy, unique, finite and conserved— and a single dynamical object, everything else follows:

- 1 equation: $F1$, the single dynamical object
- 6 axioms, fixing what the medium is
- 3 primary quantities: the density ρ_P , the grain ℓ_P and the speed c
- 74 chained derivations
- 63 with the chain proved at least at its core —and 39 with the whole proof finished, with nothing left to round off—
- 27 laws, constants and facts from the books, chosen for the list because they are recognizable and carry weight —the program derives quite a few more—
- 342 claims inside those derivations, each with its degree of certainty stated in the mathematical compendium
- 203 of them with the proof closed: three out of every five
- 97 with the core of the argument proved and an algebraic finish still to be done
- 37 say *calibrated*: not one single fitted coefficient, but the yardstick we measure with or the hour the medium marks
- 5 remaining: three hypotheses declared as such and two referred to a loose end
- 20 loose ends —the program's agenda—, each with its name, its place and its class, and none of them a debt on which anything already derived depends
- 0 coefficients fitted to the data

With no fitted coefficients, each of the seventy-four (74) links follows from the previous without inserting new assumptions along the way, and none of them has a knob where a difference could be absorbed. What *is* taken from the world is two numbers to translate the units of the medium into ours, and the reading of where the cosmos stands today along its path. None of them is a number of the law. And the split is published in full, claim by claim: there is not one that does not state how far it is proved. It is the bookkeeping that lets a program be reviewed without having to believe in it.

It hits with the full number, and with no parameters. The program's successes are of two kinds. The first are *exact coefficients*: the theory does not reach a law “up to a factor,” but with the full number in front. Heisenberg's minimum of uncertainty comes out with its factor one-half; the Chandrasekhar limit, with its entire coefficient; Tsirelson's bound on quantum correlations, exact; the time-stretching of distant supernovae, exact and confirmed by the data.

The second are *predictions without parameters*. The proportions of the cosmos —how much dark energy, how much matter in all, and how much of it is dark or ordinary— come out of the geometry of the crystal and a single reading of the clock. All four fall within one and a quarter standard deviations of what the satellites measure; dark energy and total matter, which are a single comparison, within three tenths, and dark matter within less than a tenth, with not a single knob to turn. A standard deviation is the typical error margin of the measurement: one or less is as good an agreement as the measurement allows, and from three on the difference demands an explanation.

In the entire tree of results, what is taken from the world falls into two families. The first is the

yardstick: the two numbers that translate the medium's units into ours. Their value says what our meter is like, not what the Pleno is like, and no theory—not the established ones either—can derive it.

The second is the **positional reading:** where this universe stands today along its path, the analogue of the hour a clock reads. The program takes that position from the world, and nothing more than that position. And a position along a path is read with two different instruments, both of which are needed. One measures *inward*: what part of the content of the cosmos we do not see moves today in unison, a fraction between zero and one. The other measures *outward*: the Hubble constant, the rate at which the universe expands.

Neither of the two follows from the other, because they measure things of incomparable sizes, and the merit of the program lies in having separated them: once that position is known, the densities of the universe and the whole curve of its expansion are fixed with nothing else retouched. The program also publishes the ledger of those readings, each in its place: two quantities of state—the occupancy, read inward, and the arc traveled, read outward—, a scale that was frozen into the constituents of matter when matter formed, and that is read in the proton, and the yardstick. Not one parameter of law. No coefficient of the theory is fitted to the data. And in the whole quantum chain, from Planck's constant to the ceiling on correlations, there is not a single calibration: not one number borrowed from a measurement to make the computations come out.

And it hits not once, but many times. Reaching a known law from a new origin could be lucky chance. But PIU- Ψ reaches twenty-seven (27), toward phenomena with nothing to do with one another. A lock pick opens many locks because it adapts to each one; a key with fixed teeth that opens twenty-seven different locks says something else: that all twenty-seven have the same mechanism inside. When a single idea reproduces the quantum world, the mass of the stars, electromagnetism, the radiation of a hot body, and the proportions of the cosmos, at some point it stops being reasonable to speak of coincidence. It is what scientists call *unifying power*.

Someone has tried to derive each of those laws singly at some point, and in some cases it can be done. What has no precedent is obtaining them **all from the same object and with not a single free coefficient**, so that the number delivering the gravitational constant is the one entering the quantum constant, and moving a piece to save one sector wrecks the rest. That, and not the length of the list, is the program's claim.

Which sectors it succeeds in, and why it matters that they are these

Sector	What it delivers	What it is checked against
The two constants	the gravitational one and the quantum one (G and $\hbar$), from the density of the medium, its grain and the speed of light, with the number in front equal to one	the measured value of both, with nothing left over: what is checked is that number in front
Gravity and the shape of space	how matter curves space and time: Einstein's equations entire, with the number that heads them (the complete $c^4/16\pi G$); and the interior of black holes	the race between the light and the gravitational wave that arrived together in 2017 (GW170817), equal to seven parts in ten million billion; the interior, no data yet
The quantum world	Schrödinger's equation as an exact equivalence of the medium itself, the limit of what can be known at once ($\hbar/2$), the ceiling of the correlations ($2\sqrt{2}$), the rule that turns the wave into probability (Born's) and the equation of the electron (Dirac's)	the experiments on Bell's inequality, in quantum optics
Forces and matter	electromagnetism with its 8/9 coefficient and the structure of the nuclear forces (Maxwell and Yang-Mills); whole charge and the neutrality of the atom; the refusal of two electrons to share a place (Pauli); the three quarks	the null photon mass; neutrality, to one part in 10^{21} ; the proton radius with a single input, 0.851 femtometers against the 0.841 measured
Heat	how the particles of light and those of matter share out their energy (Bose-Einstein and Fermi-Dirac) and how much a hot body radiates (the Stefan-Boltzmann coefficient), by pure counting	the viscosity of the quark plasma, inside the window; that of ultracold gases, above it and in the order the same medium fixes
The stars	the mass at which a white dwarf collapses	1.456 against 1.44 solar masses
The cosmos	the proportion between dark and ordinary matter ($\sqrt{3}\pi$), the four densities of the cosmos, the curve of the expansion ($H(z)$) and the time-stretching of supernovae	the Planck satellite, the DESI galaxy map, the supernovae of the DES survey
The beginning	a universe that contracts, bounces with no singularity off the upper wall of the medium and, on the way back, forms the particles	no data yet: it is a prediction

That list weighs more than its length for three reasons. **No two of those sectors share an instrument.** A gravitational-wave interferometer, a quantum-optics bench, a heavy-ion accelerator and a map of the sky cannot be wrong in the same way, so hitting each one is not one hit repeated but independent hits. **They cannot be fixed separately.** The coefficient that delivers G is the same one entering $\hbar$, and the number that fixes the ceiling of the well is the one reappearing in the share of the cosmos; moving a piece to save one sector wrecks the others.

They do not all weigh the same. The quantum results take not one number from any measurement. Those of the cosmos all rest on the same datum: the hour the clock of the universe reads today. And the forces-and-matter one gives the size of the proton from a single input datum, with an error of a little over one percent (1.19%), not in the fifth figure.

Formulas this short resemble numerology in form, and part from it at the decisive point. The Titius-Bode law ordered the distances of the planets with an elegant formula that hit well enough for a planet to be sought on its strength—and that nobody today regards as a law—. Eddington spent years on the “large numbers”: coincidences among enormous cosmological ratios that seemed to demand an explanation and had none. With enough combinations of π , roots and small integers, something will eventually coincide with something.

The two stories share a trait: the formula was sought after the number was known, and no mechanism tied it down. Here none is sought: each one comes out of F1, and the computation that gives one gives the others too.

The objection, moreover, can be measured, and with two distinct questions: how many simple formulas would land on these values by chance? and how many complete theoretical frameworks would reproduce the *whole* set of facts? Both counts leave chance far behind. The first disfavors it by a factor of some six hundred and seventy thousand (6.7×10^5); the second, by some thirty-four thousand (3.4×10^4), which is still sixty-five (65) under the assumption most adverse to the program.

What if it were all chance? Two counts that disfavor it

[METHOD]

Counted in two different ways, chance explains the successes far worse than the structure of the program does, even under the most adverse assumptions.

They are two distinct questions, which is why their results are neither multiplied nor averaged.

The narrow question: how many *formulas* would land there? The computer is asked to write out every formula that can be built by combining the ingredients numerology habitually uses —1, 2, 3, 4, π , and e , which is another fixed number like π — with sums, subtractions, multiplications, divisions and roots, chaining up to five operations. There are 3778 distinct formulas.

Then one counts how many of them fall, by chance, inside the error bars of the observed values. That two of them should hit both $\sqrt{3}\pi$ and f_c at once, within the margin the measurements allow, has a probability below 3×10^{-4} . And counted over the whole enumerated space of expressions, reading those two ratios as lucky formulas is disfavored by a factor of some six hundred and seventy thousand (6.7×10^5).

The broad question: how many *theoretical frameworks* would reproduce the set? It is answered with a Bayes factor —the tool for comparing hypotheses that Harold Jeffreys built on Thomas Bayes’s rule—: how many times more probable the set of successes is if there is a real structure behind it than if they are coincidences. On the scale of Robert Kass and Adrian Raftery these factors are read with, from twenty (20) up one speaks of strong evidence, and from a hundred and fifty (150) up, of very strong; here it serves only as an order-of-magnitude reference.

Fifteen (15) results go in, admitted under four criteria fixed *before* counting: that hitting or missing be genuinely distinguishable; that no room be left to retouch anything; that the value to be hit was published beforehand; and that the measurement come from an instrument not already used for another of the successes. The fifteen are read, in fact, with fifteen instruments that share no mechanism.

Another fourteen (14) are left *out* of the count, not for being incorrect, but for not contributing independent evidence. The result:

$$\text{BF} \approx 3.4 \times 10^4, \quad \text{range [65 to } 1.2 \times 10^9 \text{]}$$

The range takes in how severe the penalty for shared links is made.

What that penalty discounts. It discounts counting the same link twice when it appears in several results, which is what would inflate the figure artificially. The economy of the framework is charged elsewhere, and in its favor: a single equation with no knobs makes every result come out *forced*, and that is why each individual probability is small. A framework with a different structure per domain would tune each sector separately and would have far larger probabilities —hitting is easy when the structure was designed for that domain—. The small probabilities and the correlation among results have the same cause, and one cannot keep the one without paying for the other.

The check. Tripling *all* the probabilities and applying a severe penalty as well, the factor stays above 10. Tripling those probabilities is to concede that hitting the mark by chance was three times easier than estimated, which is the concession that most favors coincidence. Under the most punitive assumption —equivalent to declaring the fifteen (15) results almost a single fact— it still equals 65. And removing one result at a time, no individual omission drops it by more than a factor of four and a half (4.5).

The other half of the record: the coincidences that are not used. The program also records the ones it found and discarded. Two averages over the same band of vibrations of the crystal coincide to three parts in a thousand (0.7253 against 0.7231), and even so they are not used: on deforming the crystal they separate in opposite directions, and twenty-four (24) simple formulas land just as close. And when two quantities from different sectors coincide to five figures —the period of the modulus vibration and the half-wavelength of its static response—, the coincidence is resolved in closed form: the two would be exactly equal if the curvature of the well were twenty (20), and since the difference enters squared, a distance of one and a half percent (1.5%) becomes three parts in a hundred thousand (3×10^{-5}). Origin decides, not proximity.

What this changes. What these two counts establish is that the alternative explanation —that the successes are numerological coincidences— is disfavored under any reasonable choice of assumptions, including ones designed to hurt the program.

To this is added the coherence across sectors: that the same medium, with the same two scales, yields at once the gravitational constant, the quantum constant, the exact Heisenberg minimum, and the mass at which a star dies.

Each result is developed with its explicit mathematics and carries its degree of certainty in a label. Where the argument is entire but a computation remains to be closed, the label says so. And when the program leans on a result that is not its own, it takes it as published, with the name of whoever obtained it, without touching a single number of it to make it fit.

What each label says

[DERIVED]	complete proof, with no gap: the result follows step by step from F1 —such as the gravitational constant, which comes out of the firmness of the medium and the size of its grain—
[SLD]	strong logical deduction: the argument is entire and with no conceptual gap, and what is missing is closing a computation. It is more than a conjecture and less than a proof
[CALIBRATED]	value anchored to a measured datum, with the datum stated —such as the hour of the cosmos, which is where the medium stands today along its path—
[METHOD]	a matter of method: it states no result of its own —such as the count of how much chance would explain—

They sit in the header of each blue box. A box with two labels separated by a slash splits its content between the two.

The checking answers **two distinct questions**, and they must not be confused. The first: does the book say the same as the computation returns? There not a single figure of difference is allowed, and none of the checks may fail. The second: does the computation coincide with what has been measured in the sky or in the laboratory? That one only makes sense where there is something measured to compare with.

An equality such as that of G admits no agreement figure, and the reason is this: since the program's yardstick is fixed precisely with G and with $\hbar$, the formula returns the measured value of G whatever happens, by the very way it is put together. The only thing that can be checked there is the number in front, and that number comes out one.

Checking a program like this has a concrete shape. It is not enough for the author's computations to close: a code written separately, carrying no answer inside it, has to do them again from the start and obtain the same.

How it is checked, and what remains open

The verification is done by three computational notebooks that ship with the package, and that anyone can download and run.

The **numerical** one recomputes from their first-principles formulas the quantities of **six hundred**

and seventeen (617) rows and issues six hundred and forty-eight (648) verdicts: five hundred and seventy-three (573) against the corpus and seventy-five (75) against the compendium. It declares only ρ_P , ℓ_P and c , and obtains G and $\hbar$ inside the notebook itself; it also carries a control row that *reads its own code* and fails if either is reassigned by hand. More than three out of every five of its rows (373 of 617) **touch no human yardstick at all**: they are pure numbers, and in a pure number there are no units where a mismatch could hide.

The **symbolic** one redoes **three hundred and twelve (312) claims** with the symbols instead of the numbers, so that no rounding can cover up an error, and almost all its rows (192 of 194) carry the wrong alternative alongside: the row passes only if the two give different results. The reason is that a check can pass without checking anything —if the correct formula and a wrong one return the same number, the row would have passed with either of them—. Requiring that they disagree guarantees that the row discriminates. The two remaining rows carry the mark “by construction” and their reason.

The **auditor** sweeps the sources of the four documents and compares **four thousand nine hundred and five (4905) printed figures** against their *closed form*: the exact formula that figure comes from, written with fixed numbers and nothing else, with no value taken from a measurement. Discrepancies: **none**. It has two blind spots, and it declares them. It cannot assign a printed figure with fewer than four figures of precision to its formula —1.456 has four; 1.4, two—. And it does not recognize as its own a figure that departs from its closed form far beyond its last decimal: such a figure stays “uncataloged” rather than being flagged as an error.

All three also run in self-test mode with faults introduced on purpose —a decimal changed in its last figure, a sign inverted, a constant displaced— and are required to catch them all.

How far each thing is proved. A derivation is made up of several claims, and each one has stated separately how far it is proved; that is why there are many more labeled claims than the seventy-four (74) derivations. Of the **three hundred and forty-two (342)**, **two hundred and three (203)** have the proof closed —three out of every five— and **ninety-seven (97)** more have the core of the argument proved, with an algebraic finish still to be done. Another thirty-seven (37) lean on a measured number, and they are the usual ones: either a number to translate the units of the medium into meters and kilos, or the hour the clock of the cosmos reads today. The remaining five are three hypotheses declared as such and two referred to a loose end.

The open questions —the *loose ends*, in the program’s vocabulary— are **twenty (20)**, each with the exact criterion by which it would be closed and with its class declared, and none of them is a debt on which anything already derived depends. Five are confrontations with measurement, which a datum can decide; fifteen (15) are of enrichment, work that extends the program without anything already obtained resting on it. Listed apart are seven that depend on another loose end, one verification path open to whoever wishes to follow it —simulating F1 on the lattice by the Monte Carlo method— and five declared frontiers, which mark where the reach of the program ends.

At the end of the book, one entry for each of those twenty-seven (27) results says what each law is, whose it is, what it lets us do and against what it is contrasted.

Behind every claim there is, moreover, a complete formal development: a corpus of six hundred and thirty-four (634) pages where each derivation is done step by step, and a mathematical compendium that condenses the proofs with their intermediate algebra and unit analysis.

19. The language in which the universe operates

The numbers the program derives all have the same family air, and each one comes with a name of its own behind it. The proportion between the two kinds of matter in the cosmos is $\sqrt{3}\pi$; the coefficient of electromagnetism, $8/9$; the floor of the medium, $12(\pi^2 - 4)/\pi^4$; the ceiling on quantum correlations that Tsirelson fixed, $2\sqrt{2}$; the stiffness of the medium against bending, $1/40$; and the number that heads Einstein’s equations, $2 \times 4\pi$.

None of them is an arbitrary figure with many decimals. They are all *ratios*: one area divided by another, a sum over the faces of a tetrahedron, the measure of a sphere of directions. And always the same pieces — π , a few roots, small integers counting neighbors or vertices— recombining.

That is what the numbers of a theory look like when it does not measure them but reads them off a geometric shape. And it shows that the magnitudes of the Pleno are written in a *language*: a few elementary words—the geometry of the cell, the number of neighbors, the measure of the sphere—and fixed rules for combining them.

The difference between having a list and having a grammar is the same as between memorizing loose sentences of a language and learning to speak it. In ordinary physics the constants of nature are measured and accepted: they are sentences one repeats without understanding. Here one can ask *why* a number has the value it has—and sometimes anticipate what its value will be, from its place in the grammar, before computing it another way—. A grammar does not only account for what is already written: it lets one write new sentences. That is the difference between reading the universe and understanding the tongue it is written in.

Pure numbers: constants that need no yardstick

[DERIVED]/[SLD]

Some constants have to be measured, and some are read off a geometry.

Almost every quantity in physics carries units and, with them, a yardstick chosen by convention: a meter, a kilogram. A *pure number* is a quantity the medium produces with no yardstick at all—any civilization, in any system of units, would obtain the same number—. That the program generates them is what allows speaking of a grammar rather than a list of measured constants.

The proportion between dark and ordinary matter is $\sqrt{3}\pi$: the area of a sphere divided by that of the tetrahedron inscribed in it, with the factor two the fermionic character of ordinary matter contributes. The coefficient of electromagnetism is 8/9: what the sum of circulations over the faces of the lattice returns. Neither is measured: both are read off a geometric form, and only afterwards checked against the world.

In the thermal sector the units go away on their own, and one can see how. The viscosity bound of Kovtun, Son and Starinets—the one no measured fluid has undercut—is normally written with Planck’s constant and Boltzmann’s, and the Pleno’s own viscosity floor falls exactly on it: measured in units of that bound, the medium’s window starts at exactly one. The ceiling the Pleno sets at the other end of the window is $4\pi/5$, and the medium falls inside with nothing adjusted: at its maximum temperature, thirty-two percent (32.32%) above the floor. And there is a third pure number: the one that compares how long the medium takes to react when it is shaken with the fastest rhythm at which heat can make it vibrate,

$$\frac{5\sqrt{5}}{2\pi} = 1.7794,$$

with not a single free symbol. The same happens with the coefficient that fixes the depth of the well, $E_0 = 4.2546 \rho_P c^2$, whose number is closed in π and $\sqrt{6}$, and with the point at which dark energy equals matter, $\sqrt{2} S_{\min} = 1.0226$ (the share-out fixes that point in closed form; when it is crossed is told by today’s reading).

What this changes. When a constant comes out as a pure number, it stops being a datum that must be measured and becomes something that can be *read*: one sees which geometry it comes from and why it could not have been otherwise.

20. The cosmic clock: reading the hour of the universe

There is a number astronomy measures with care: the rate at which the universe expands, known as the Hubble constant, H_0 , after Lemaître, who posed it in 1927, and Hubble, who measured it in 1929. In ordinary physics it is a datum that is measured and accepted—one more number in the list of “it is so”.

In the Pleno, time is the pulse of the medium, counted in tiny “ticks”—the smallest physics knows, the so-called Planck ticks—. The expansion rate of the universe is not a fundamental ingredient, but a *reading*. PIU- Ψ gives for that rate a closed formula with three pieces: the geometry of the Pleno, the rhythm of the Planck tick, and the state the medium is in today. The first two come entirely from the theory; the third is the reading of the cosmic clock at

this moment. Read with today’s hour, that formula returns **sixty-seven (67) kilometers per second per megaparsec** —each megaparsec of distance, some three million (3.26×10^6) light-years, adds sixty-seven kilometers per second to the speed at which a galaxy recedes—, which is the value the satellites measure.

That number is not an eternal constant engraved in nature, but the reading of a clock at a given instant —the “hour” of the cosmos—. Asking “why is the expansion exactly that and not something else?” is like asking a clock “why is it three and not five?": the clock’s mechanism is the theory’s business, and the theory has it; the particular hour depends on where the universe is along its path. The whole curve is theory; the point of the curve we are at today is what the clock reads now.

This defuses one of the greatest scandals of modern physics: the factor of 10^{123} between the vacuum energy that quantum theory predicts and the one actually observed, which has been called “the worst prediction in the history of physics.” Read from the Pleno, that monster is tamed, and the count can be followed in three steps.

First: the density of the cosmos goes with the square of its expansion rate. Second: that rate is, roughly, one divided by the age of the universe —the older it is, the more slowly it expands—. And third: that age, counted in Planck ticks, is an enormous number. Chaining the three, the density of the cosmos compared with that of the medium comes out as one divided by the square of that enormous number. The 10^{123} stops being an impossible fine-tuning and becomes the age of the universe in ticks, squared. It is still a gigantic number; what it no longer is is a mystery.

The stretching of the medium has a consequence already measured. When a distant supernova explodes, its brightness rises and falls over some weeks. Since the universe has been expanding while that light traveled, we do not see that rise and fall with its original duration: we see it *stretched in time*, like a film played more slowly.

The light itself arrives stretched —its wavelength grows, and its color shifts toward the red—, and the prediction is clean: the duration of the explosion stretches by exactly the same factor as the wave. If the light arrives with its wave doubled, the explosion lasts twice as long. Astronomers write that stretching as the light’s stretch factor raised to an exponent, and the DES supernova survey measures it over one thousand five hundred and four (1504) of them (White and collaborators, 2024): 1.003 ± 0.011 . The theory says 1, exact and with no parameter at all.

Light that simply grew tired along the way would give 0. That was the classic alternative to expansion, the “tired light” Fritz Zwicky proposed in 1929: that light lost energy crossing space and reddened without anything stretching; the wave would then arrive lengthened, but the explosion would last as long as it lasted. The standard model also gives 1, because it assumes it by postulating a space that expands; here it comes out of the medium. That is agreement to a quarter of a deviation (0.27σ), tired light is ruled out at some ninety (90), and the duration of an explosion cannot be adjusted.

The hour on the cosmic clock

[DERIVED]/[SLD]

The expansion rate has a formula in three pieces, and only one of them is taken from the world.

The formula is

$$H_0 = \sqrt{\frac{8\pi}{3}} \frac{c}{\ell_P} \sqrt{\Theta_0} ,$$

the product of a geometric constant, the rate of the Planck tick c/ℓ_P —the fastest clock there is— and Θ_0 , which is today’s position read outward, in scale —the share-out of the cosmos is the other reading, inward, in amplitude, as f_c ; they are two instruments on the same travel, and neither turns

into the other—, and it equals

$$\Theta_0 = \frac{3}{8\pi N_{\text{tick}}^2} \approx 1.66 \times 10^{-123}, \quad N_{\text{tick}} \approx 8.5 \times 10^{60},$$

where N_{tick} is simply the age of the universe counted in Planck ticks. With that reading, the formula reconstructs the 67 km/s per megaparsec the satellites measure. And it is not a separate clock: it is the identity of the speed limit, read in reverse—the same relative haste of the medium that on the small scale sets the speed of light, on the large scale tells the hour—.

With the position fixed, the entire history of the expansion is decided by the shape of the well, with no margin to retouch it. Against the distances measured by DESI, a map of millions of galaxies, it gives $\chi^2 = 6.54$ against 6.53 for the standard model—statistically identical, with the same degrees of freedom, but with parameters derived rather than fitted—. The χ^2 adds up, point by point, the square of how far the curve departs from each measurement, counted in units of its error: a curve that passes well through n measurements gives a χ^2 close to n . The degrees of freedom are the measured points minus the parameters fitted with them: what is left of the test once what the curve was able to accommodate is discounted. That tie is not a tie. The standard model reaches its figure with parameters that come from fitting it to other data; the shape of the Pleno’s curve is written in advance by its well, and it has nothing to move. And the time stretching of distant supernovae comes out exact, $b = 1$ against the observed 1.003 ± 0.011 : agreement at 0.27σ with no parameters at all.

The check. The formula has no margin; what could fail is the curve on which it is read. With the age the fit to the microwave background assigns to the universe, a background expanding at 73 km/s per megaparsec would require a universe older than its own Hubble time—one divided by the expansion rate, which is the age the universe would have if it had always expanded at today’s rate—: 1.03 times that time. A medium with $w = -1$ and the program’s matter fraction reaches 0.953, and no more. The 67 fall inside, with nothing forced. And there is a clock that does not pass through the fit of any model: the age of the oldest stars. If they exceed thirteen and a half billion years (1.35×10^{10}), the same curve does not admit a background above 69.

What this changes. A model that fits that number cannot say why it takes the value it takes; a formula that reads it as an hour can: it takes that value because the universe stands where it stands along its path.

That reading also puts in order a puzzle that vexes astronomers. Measuring the expansion rate in two ways yields different numbers. One infers it from the cosmic microwave background, the oldest light in the universe, emitted when it was some three hundred and eighty thousand (380000) years old, read with the standard model, and gives about sixty-seven (67). The other measures it in the nearby universe, step by step, with stars and supernovae whose distance is known, and gives about seventy-three (73). They call this discrepancy “the Hubble tension,” and in the usual model no one knows how to explain it.

PIU- Ψ says two things about it, and the first calls for a distinction that usually gets lost in the debate. The seventy-three (73) of the nearby universe is a correct measurement of what it measures: the rate at which the galaxies we have at hand are receding. What is in dispute is not that measurement, but something else: which of the two numbers is the *background rate* of the entire universe. And there the program comes down on the low one.

The high one is ruled out as a background, and not by preference. With the age assigned to the universe, and with the amount of matter the program derives—a little under a third of the content—, a background of seventy-three (73) would require the universe to have expanded more slowly in the past than now, and only a dark energy whose density grows with time can achieve that; a medium relaxing toward its rest cannot produce one. The sixty-seven (67), by contrast, the Pleno’s curve accommodates with nothing forced. And the ruling-out has room to spare: it holds up against four times what that amount of matter can vary within its own margin.

The second is that the incompatibility—the “tension”—is not a physical anomaly demanding new matter or new forces, but a mirage produced by the measurement method itself: an effect

that is not in the sky, but in the way of reading it. The sixty-seven (67) of the microwave background is not a direct reading: it is the value the standard model needs for that background to fit, computed with its *template*, the shape of expansion curve the analysis takes for granted in order to turn what it sees into numbers. When that template is applied to a medium like the Pleno, which is not the one it was built for, the two ways of measuring seem to clash even though the background is a single one: the gap between sixty-seven and seventy-three (73) appears because of the mold through which the data are read, not because the universe hides two competing rates of expansion.

From that comes a prediction, with its sign stated: that discrepancy must *attenuate or dissolve* when the expansion is measured with observables that do not pass through that template. There is one at hand. A sphere of galaxies measures the same across as along the line of sight, and comparing those two measurements requires no borrowed ruler. If the expansion history used to turn angles and redshifts —how much the light has reddened along the way, which is the way to know how far off what one is looking at lies— into distances is the wrong one, the sphere comes out flattened.

The same holds for the other piece of news in recent cosmology: that dark energy may be weakening. DESI, a survey that maps millions of galaxies to follow the expansion over billions of years, hints at it when it combines its data with those of the microwave background and the supernovae. The program holds that this signal is the same kind of mirage —the reflection of forcing a constant dark energy into a mold that expects a variable one—, and that it attenuates once measured without that mold. Measured on that shape of the structures in the sky, with no borrowed pieces, the signal falls to less than half. It does not vanish.

That idea — H_0 as an hour and not a constant— settles four things at once. It stops being a mystery why the expansion has exactly the rate it has. The “one followed by a hundred and twenty-three zeros” becomes a count of ticks, squared. The seventy-three (73) is excluded as a background value. And the exponent with which the light curves of distant supernovae stretch comes out exact. Three things the standard model cannot do and one it only assumes; here they fall together because they were not four problems.

Three anomalies reduced to a single fact

[DERIVED]/[SLD]

The three anomalies are the same medium read with a template not its own: a clock being asked for a constant.

None of the three arises from a badly made measurement. The data are good and say what they say; what changes is the mold through which they are turned into numbers, which is the standard model’s and not the Pleno’s.

The worst fine-tuning in history. That factor of 10^{123} is Θ_0 turned upside down: the square of the age of the universe measured in Planck ticks. There is nothing to cancel.

The H_0 of the young universe. Here is the key to both anomalies, and it is that the two numbers are not of the same kind. The local value, around 73, is a measurement: it is obtained step by step with stars and supernovae. The value attributed to the primordial universe, around 67, **is not measured**: it is the number the standard model needs for the pattern of the cosmic background to fit, and to obtain it one has to assume an expansion curve in advance and integrate it. The famous discrepancy does not, then, compare two measurements: it compares a measurement with the output of a fit. Change the curve that is assumed and that output changes, and not because the sky has changed.

DESI’s “variable” dark energy. A medium resting still, with its w pinned at -1 , looked at with a mold made to catch changes, leaves exactly the leftover the analyses are reading as a change.

What this changes. The literature treats them as three independent problems, each with its own family of proposed solutions. Here all three are the reading of a single medium, which marks an hour instead of keeping a constant, done with a template that is not its own. The measurements are

still good; what does not fit is the mold. And none of the three calls for an added ingredient.

The test without a ruler: the ratio that cancels what is borrowed

[DERIVED]

Almost every cosmological comparison needs some ruler borrowed from another model; dividing one distance by another needs none.

When a theory is compared with the data of the cosmos, it normally drags along things it did not derive: the sound horizon —the distance sound managed to travel in the primeval plasma, which stays imprinted in the distribution of galaxies and serves as a ruler in the sky—, the calibration of supernova brightness, the template used to fit the curve. If the agreement comes out well, one never quite knows how much is owed to the theory and how much to what was borrowed. The structures of the sky have, on average, no preferred direction: a sphere of galaxies measures the same across as along the line of sight. If a wrong expansion history is used to convert angles and redshifts into distances, the sphere comes out flattened or elongated (this is the Alcock-Paczyński test). The same structure is measured in the two directions and the ratio is taken:

$$F_{\text{AP}}(z) = \frac{D_M(z)}{D_H(z)} = E(z) \int_0^z \frac{dz'}{E(z')}.$$

In it, z is the redshift, which marks how far away one is looking; D_M and D_H are the distances inferred from the width across and from the depth along the line of sight, and $E(z)$ is the expansion rate at that time divided by today's. Dividing removes the absolute scale, the sound horizon and every calibration; only the *shape* of the expansion curve survives, which is what the derived potential fixes.

On that observable the program has no freedom whatsoever: its two inputs —the matter fraction, $\Omega_m = 1 - f_c = 0.3131$, and the equation of state of the background, $w = -1$ — are fixed before looking at the data. Against the six redshifts DESI DR2 publishes,

$$\chi^2 = 6.669 \text{ over six points and no fitted parameter,}$$

that is, 1.111 per degree of freedom, and no point deviates by more than 1.69 times its error.

The same comparison serves to measure the variable-dark-energy signal without the borrowed infrastructure. On the bare data, letting the equation of state vary improves the fit by barely $\Delta\chi^2 = 1.66$ —at most 1.3 standard deviations—, against the 2.8 to 4.2 reported by the analysis that combines DESI with the microwave background and the supernovae. Stripped of the borrowed pieces, the signal attenuates; it does not vanish.

The check. Replacing the program's fraction by $\Omega_m = 0.35$ raises the χ^2 by 6.86. The curve does not accept just any value.

What this changes. A theory that fits well may simply be fitting well because it has the means to. Here there are no means: the curve is written before the data are looked at, and the data do not move it. That said, what “nothing fitted” means here has to be stated with care. The point along the path where the medium stands today is indeed taken from the world: it is the hour on the cosmic clock, and it is read once, before everything else. What was not touched was anything to square with *these* particular galaxies: the curve was already written when they were looked at.

The 1.3 standard deviations that survive are not produced by the medium, and one can say why. The two walls of the well —the ceiling above, the floor below— only make themselves felt while the medium is going down toward the bottom; once settled on the bottom, they are so far away that they do not touch it. And the medium has been settled there since shortly after the bounce: when a telescope looks as far as it reaches, what it sees is a medium that has been at rest for a number of Planck ticks with sixty (60) zeros. Its correction to the expansion curve, at those distances, is exactly **zero**. And no sector of the Pleno can move the background away from that rest. What remains open is of another kind. That scrap of signal appears in the bare data, and grows to three or four deviations in the analysis that puts the galaxy map together with the microwave background and the supernovae, where reading each piece takes something for granted. Whether it comes from the measurement itself or from the template that joins the

three is decided by the bare data, with their full covariances and no template.

21. The cycle: the ending, the bounce, and what was fixed in it

The word “expansion” does not mean the same thing in the two descriptions. In the usual picture, space *is created*: the universe is a stage that grows larger, and it can grow without end. In the Pleno there is no stage to enlarge. What we call expansion is the medium stretching, and the number of cells in the medium does not change: they are the same ones as ever, only ever more stretched. It is the difference between living tissue that grows by making new cells everywhere and an already-woven mesh that stretches, where not one further thread appears.

That difference decides the ending. A stage that is created can keep growing forever; a mesh that stretches ends up giving all the slack it had. And the physical reason is the same. On an energy curve, what pushes is the *slope*, not the height. A ball placed on a hillside rolls; placed at the bottom of the valley it stays still, even if that bottom is a thousand meters above sea level. What moves the expansion of the universe is not, then, how much energy there is on the floor of the well, but how steep the ground is where the medium finds itself. And at the bottom it is not steep. The floor stays where it is; what disappears is the slope that remained to be descended.

So **the expansion does not go on forever**: the rate at which the universe stretches tends to zero. There is no de Sitter destiny here of the kind the standard model has—in which the expansion settles at a positive rate, accelerates indefinitely and galaxies end up losing sight of one another—. The two descriptions agree on what can be measured today, and diverge completely in the future.

The cycle has two phases: the *crunch*, the great squeeze, and the bounce.

Not everything cycles. The Pleno is divided into two populations that behave in opposite ways. The condensate at rest—dark energy, sixty-nine percent (69%) of the content—is homogeneous and **does not clump**: in it pressure re-equilibrates at the speed of light, so that a local excess flattens out before it can even form, and gravity has nothing to pull on. For that reason it takes no part in the collapse: it is the ocean, which does not pile up. Matter—the remaining thirty-one percent (31%), the ordinary and the dark together—is the only thing gravity concentrates, and the only thing that cycles: it is the waves, which rise and break upon it.

From this follows as well **why the universe does not collapse whole**: more than two thirds of its content does not clump. Only the thirty-one percent (31%) can fall, and the matter available for each cycle is bounded by that same fraction.

And the motor of the crunch is gravity. Not the local gravity of a cloud of matter—that falls short by some six hundred thousand times (5.9×10^5)—, but the gravity of the entire content acting at once: the contraction of the universe as a whole. On contracting, the medium is compressed; compressed, it climbs its wall; and from there it turns back. That is the cycle.

Why there cannot be a singularity. The usual story begins at an instant of infinite density out of which everything comes and in which the equations cease to mean anything. In the Pleno that cannot happen, for the same reason as with black holes: the medium has a compression ceiling, and the energy it costs to approach it grows without bound. Since the energy of the universe is finite, the compression always stops short: where the upper wall of the energy curve equals the energy there is, the medium turns around. That does not depend on any brake or any viscosity: the very shape of the curve guarantees it. A contracting universe does not end at a point. The medium resists, gives back, and **bounces**. What we call the beginning is the instant it turned around.

What does the compressing. It cannot be the region’s own gravity. Driving the medium to the region of the wall demands an energy density of some one thousand six hundred and eighty

(1680) times the Pleno's own; the most that the gravity of a dense region of matter can supply is 0.0028 of those same units. Short by 5.77 orders of magnitude —almost six hundred thousand times—. A region collapsing under its own weight does not come close: it stabilizes barely above the floor and stays there. What compresses the medium to the bounce, therefore, is the gravity of the whole universe contracting at once, not that of a region on its own.

And what viscosity does. The wall does the turning; viscosity decides how the turn is made. The medium's resistance to abrupt changes grows the faster it is forced to deform. It is the cornstarch again: a finger sinks in if pushed slowly, and bounces off if struck. In the bounce, the energy the compression stored is released all at once: the deformation speeds up, the viscosity grows with it, and the energy left over stays in the medium as heat.

Without that growing viscosity the medium turns around all the same, because the wall does the turning, but it comes out deforming on the order of a thousand times (10^3) faster than the maximum rate at which it admits a shear. That is not an impossibility: the bounce is a dilation equal in every direction, with no shear, in which nothing has to propagate from one point to its neighbor, and that haste is the energy of the compression turned into motion. With the viscosity, the numerical integration —letting the computer follow the equation instant by instant and see where it leads— shows the deformation approaching that maximum rate and never reaching it, wherever the bounce is released from.

And that is why the bounce is clean. The medium does not rebound several times against the wall, nor is it left vibrating beside it. Today, at rest, the medium is *very* lightly damped. There is a scale for measuring that: when the damping equals one, a system pushed away from its place comes back without overshooting, without a single oscillation; below one it oscillates, and the lower it is, the more times it oscillates before settling. The medium at rest has barely a hundredth (0.0116), so that if it were disturbed it would be oscillating for a very long time. And compressing it would not help: a stiffer spring oscillates more, not less.

What does the work is viscosity. Since it grows with haste, when the deformation gets nearly to its maximum rate —to 98.84%— the damping has gone from that hundredth to one, and from there on it keeps growing without bound as the haste approaches a limit no trajectory reaches. Near the turning point the medium no longer behaves like a spring: it is cornstarch struck all of a sudden, which takes the blow without vibrating. The bounce turns around once and comes out, in some thirty times the shortest interval of time the medium admits: the time light takes to cross a cell.

What was fixed on the way back. As it expands, the medium cools and crosses a point at which it *sets*. The image is water freezing: while liquid it has no directions and no structure; on crystallizing, the axes, the planes and the defects appear, and are fixed. The Pleno does something equivalent, going from the most compact geometry there is —twelve neighbors per cell, the packing of oranges at the market, which Kepler conjectured to be the densest possible and Hales proved— to the four-neighbor diamond lattice it operates with today.

That transition is not instantaneous. Reorganizing from twelve neighbors to four releases a considerable amount of heat, the same latent heat water gives up on freezing: a more ordered structure holds less energy than the one it came from, and the difference comes out as heat. And the medium cannot finish crystallizing until it has evacuated it. While it does, it sits on a *plateau*: a stretch in which conditions barely change. And that plateau is the window in which particles form.

From that it follows that every electron in the universe is identical. Standard physics attributes this to their all being waves of a single field; here that field is the Pleno, and the plateau adds why none came out different: they all formed under the same conditions, during the same plateau.

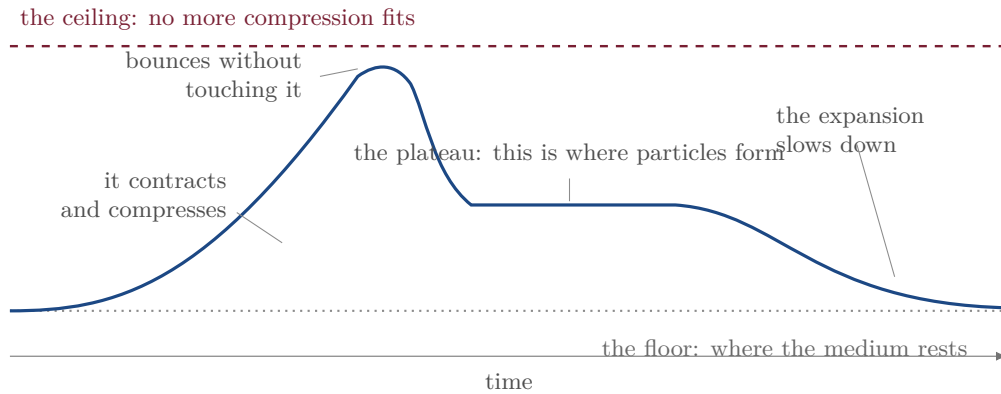


Figure 12: The cycle at a glance. The medium contracts and compresses, rises toward its ceiling without ever touching it and bounces; on the way back it stays a stretch on the plateau, which is where particles form, and then settles onto its floor, where it remains today with the expansion slowing down.

What was not fixed there. The constants of the universe were not fixed at that instant. What dark energy is, for one, does *not* come into being at the bounce: it is the phase condensate of the medium, at rest at the bottom of the well, and that bottom is there because of what the medium is, with a bounce or without one, and not one datum of cosmic history enters its derivation. What crystallization decides is the *share* between what stayed coherent and what stayed trapped as matter. How it was decided how much medium stayed in step and how much stayed trapped in knots, the program argues out as a freezing of the kind Kibble and Zurek described —regions that order themselves each on its own leave knots wherever they meet—; how much of each was left, it does not compute: it reads it off the sky, just as it reads the hour on the cosmic clock.

Each particle is one of those defects of the crystal: the same medium in another configuration, with part of the volume trapped. There is a single substance before and after.

What can be checked. That passing episode —the transient, as it is called— is not observable and cannot be: it happens with the medium close to its maximum compression, and between it and the earliest observation that exists —the formation of the first nuclei, a second after the beginning— lie forty-three (43) orders of magnitude in time, that is, with forty-three zeros in between. What is checked is not the event but the seals it engraved: out of this bounce come initial ripples of almost the same size at every scale, large and small —what cosmologists call a nearly scale-invariant spectrum—, which is just what the sky shows, and they come out **with no need for inflation**. In the standard model that work is done by inflation: an enormous expansion in the first fraction of a second, driven by a field of its own (the inflaton) postulated for the purpose. Here it is done by the bounce, which the theory already contains, and the mechanism can be followed. What ripples is not the compression of the medium —that one has a very high entry cost and is frozen— but its spin, which costs nothing to move. And during the contraction the medium behaves like dust: what it holds are countable knots, and knots that are conserved and draw together as space contracts dilute exactly as pressureless matter dilutes. That is not assumed, it follows from what matter is made of here. And with the medium behaving that way, the standard count of how ripples grow during a contraction —Mukhanov and Sasaki's, in the form that Wands, and then Finelli and Brandenberger, studied for a contraction of matter— returns, with nothing else touched, ripples of the same size at every scale. The equal size is not asked for: it comes out. On top of it, the sky shows a small tilt in favor of the large scales —the *nearly*—, and its sign the program derives: it is the sign of the medium's pressure at the moment each ripple is frozen. That it should come out on the side observed requires that moment to fall where the medium is more diluted than at rest, and dating that moment is an open loose end. The value, 0.965, is read off the sky.

Where we are, and where we are going. On the expanding branch, after the bounce. The medium crystallized, formed in that crystallization what we today call matter, and went down at once to the bottom of its energy curve, where it has rested ever since. Matter thins out; the relative weight of the background grows, because it does not dilute; the rate of expansion falls. That is the position, and that is the direction of travel.

What is missing for the cycle to close. That the end of the expansion should give way to the next contraction is an **open** piece. The equation of the cycle carries a push that comes from the whole: the contraction of the entire universe, pulling on each point of the medium. That push is in the equation, but its exact form is not deduced from the axioms, and the integration sets it to zero. That zero is a device of computation, not a result of the program.

And what the program does not say. The bounce has its equation, its derived coefficients and its numerical integration; it does not have the degree of detail the rest of the edifice reaches. Before the bounce there was a contraction, because without it there would be nothing to bounce; what there is not is a “before” of the Pleno, because “before” is a measure of change and without a medium there is no change to measure. The program describes a cycle, but **it does not claim that there has been a succession of cycles, nor how many**, because the link that joins the end of one expansion to the next contraction is missing. What the equation describes in detail is the transition this universe came through; no chain follows from that, and the program does not claim one. And it does not say where the medium came from. The program describes how the Pleno operates; it does not explain why there is a Pleno rather than nothing. That is a legitimate question, and it is outside its scope.

The bounce: the equation of the cycle and its regulation

[DERIVED]/[SLD]

A single equation describes the cycle: two motors drive it, the upper wall of the energy curve does the turning, and the viscosity of the medium dissipates what is left over so that the turn is clean.

The compression of the Pleno, looked at on the scale of the entire universe and the same everywhere, behaves as an oscillator whose resistance does not grow in proportion but ever faster—a Gent oscillator with dilatant damping—. In it, a dot over a letter means “at what rate it changes,” and two dots, “at what rate that rate changes”:

$$\rho_P \ell_P^2 \ddot{S} + \eta(\dot{\gamma}) \dot{S} + \frac{dV_{\text{eff}}}{dS} = F_{\text{ext}}, \quad \dot{\gamma} = \frac{2|\dot{S}|}{S},$$

where V_{eff} is the derived potential, η the viscosity that grows with haste, $\dot{\gamma}$ the deformation rate—how fast the medium is changing shape—and F_{ext} the push the whole exerts on each point: the cosmological contraction. Every coefficient is derived; the only term with no exact formula is F_{ext} , which the integration sets to zero. The form in which viscosity grows with haste, $\eta \propto 1/(1-x)$, is a constitutive choice, and what depends on it carries the [SLD] label.

The wall does the turning, not the brake. The potential V_{eff} grows without bound before the ceiling $S_{\text{max,geom}}$, and the total energy E_{tot} is finite and does not grow. Hence, at every instant,

$$\bar{S}(t) \leq V_{\text{eff}}^{-1}(E_{\text{tot}}) < S_{\text{max,geom}},$$

where $\bar{S}$ is the mean compression and V_{eff}^{-1} reads, on the compressed branch of the curve, which compression a given energy corresponds to. The compression never goes past the point where the wall equals the energy available. That growth is supplied by the elastic terms that carry the ceiling—the hyperelastic one and Gent’s—; neither viscosity nor its dilatant factor plays any part. [DERIVED]. The lower wall, Klauder’s, does the same on the other side: it keeps the medium from being extinguished ($S > 0$) and gives the turning point when, after the bounce, the medium overshoots its floor by inertia.

The two motors, and their asymmetry. The crunch is forced by the contraction, which happens at the size and the rhythm of the entire universe; the bounce is the medium releasing its elasticity, at the size and the rhythm of the grain. One is slow and the other extremely fast, and the asymmetry is not in the brake.

The two bars of the $|\dot{S}|$ in the equation of the cycle say so: the viscosity depends on how fast the medium is changing shape, not on which way it changes it. At one and the same degree of compression and the same haste, the medium brakes equally going up and coming down.

It is in the spring. Going up, the medium works against its own restoring force, which moreover stiffens as it nears the ceiling: the compression is uphill, and that is why it is slow, so slow that the medium has time to order itself while it happens. Coming down, that same force pushes in the direction of the motion, and the bounce is nothing but the discharge of what the compression stored. The same brake, with the spring the other way round. How much the thermal dependence near the ceiling breaks that symmetry of the brake is one of the program's open loose ends.

Why self-gravity does not suffice. With $\Delta\varepsilon(S) = V_{\text{eff}}(S) - V_{\text{eff}}(S_{\text{min}})$, driving the modulus to the region of the wall demands $\Delta\varepsilon(1.45) \approx 1.68 \times 10^3 \rho_P c^2$, while local self-gravity supplies $\approx 2.8 \times 10^{-3}$: a factor of 5.9138×10^5 , or 5.77 orders of magnitude. Integrating the equation with that force, the system stabilizes at $S \approx 0.743$, barely above the floor.

The damping ratio. With $m = \rho_P \ell_P^2$ and $k = V_{\text{eff}}'' = \xi_{\text{loc}} \rho_P c^2$,

$$\zeta = \frac{\eta(\dot{\gamma})}{2\sqrt{mk}} = \frac{\zeta_0}{1-x}, \quad \zeta_0 = \frac{1}{2\sqrt{20} S_{\text{max,geom}}^2 \sqrt{\xi_{\text{loc}}}},$$

which at today's floor equals $\zeta_0 = 0.0116$: the radial mode is heavily underdamped. Under compression ξ_{loc} grows and ζ_0 falls. The crossing to overdamped is brought not by the curvature but by the $1/(1-x)$ factor of dilatancy: $\zeta = 1$ at $x = 1 - \zeta_0 = 0.9884$, and ζ grows without bound toward the pole $x = 1$, which no damped trajectory reaches.

The check. Repeating the integration with constant damping instead of the dilatant one, and releasing from $S = 1.45$, the deformation rate reaches 3.9×10^3 in units of c/ℓ_P . That is not a violation: the bounce is homogeneous dilation and has no shear, so the bound $\dot{\gamma}_{\text{max}} = c/\ell_P$, which bounds shear, does not restrict it; that rate is potential energy turned into kinetic. Releasing from $S = 1.0329$, the compression at which the medium crystallizes, without the dilatant factor the medium overshoots its floor down to $S = 0.3865$ and takes 76.66 Planck ticks to settle; with it, only down to 0.6551, and it settles in 31.54. Sweeping the starting point from $S_0 = 0.9$ to $S_0 = 1.45$, with the dilatant viscosity x_{max} grows from 0.989 to 0.999999 without ever crossing $x = 1$, and the result does not change even if the count is redone with ever finer steps, which is the way to check that it is not a mirage of the method.

What this changes. The initial singularity is, in general relativity, a theorem: Penrose and Hawking's. Models that avoid it usually do so by adding exotic matter or choosing initial conditions. Here it is not avoided: it is *inaccessible*, because the material does not admit that compression, and the bound that forbids it is the same wall that gives the ceiling of the well and the core of black holes. That the turn happens before the ceiling is proved without leaning on viscosity, and following the equation instant by instant, with every coefficient of it coming out of the theory, carries no free number. That in that turnaround it was decided how much medium stayed in step—dark energy—and how much stayed trapped in knots—matter—follows from the argument, but how much of each was left is not computed here: it is read off the sky.

22. How far the program reaches, and what remains to be decided

PIU- Ψ is a mathematical edifice that reproduces confirmed laws and gets it right, with high precision and without adjustments, wherever it can be compared with reality. It is the work of an independent researcher, open to review by the scientific community. What is derived does not depend on what is missing, and what is not derived fits under three headings.

What is calibrated fits in two families: the yardstick, with which the medium's units are translated into ours, and the positional reading, the hour the cosmic clock shows today. And of the two, the yardstick one is closed, with a proof. Since the speed of light is fixed by convention in the system of units, exactly two anchors remain—the density of the medium and its grain—and the program proves that two is the number needed: not one, not three. The list of what has to be anchored cannot be made longer.

The positional reading also has its ledger, which says how much is read from the world and what each reading fixes. Reading where a system stands along its trajectory is not fitting its law, just as looking at the time is not building the clock. The full count is two state quantities—the arc traveled, which is the hour on the cosmic clock, and the occupation, which is the share-out between dark energy and matter—, one small-world scale that froze when the medium crystallized, and the yardstick. The rest costs zero: the medium’s compression falls to its floor from any starting point and forgets where it set out from, and its phase rests with $w = -1$. And no number in the equation is fitted to a datum: the program has not a single law parameter.

What is borrowed is not a piece of the theory, but a property of the particular thing being computed. In the Chandrasekhar limit the complete coefficient and even the number that describes how matter is distributed from the center of the star outward come out of the medium itself; what enters from outside is the composition of the star, which, put to work, turns into a prediction: a different mass ceiling for each composition.

What is open is twenty (20) loose ends, and none is load-bearing: no statement of the program presupposes it. Five are falsifiable—closing them opens a new confrontation with the world—and fifteen (15) are enrichment: they neither hold anything up nor open a confrontation, and they add detail to what is already derived. Two of them touch famous questions. One is the weak sector, the nuclear force responsible for certain radioactive decays. Each force is transmitted by a messenger of its own: electromagnetism has one, the photon, and the weak one needs three, far heavier, which are what make it so short in range. Of that sector some counts remain to be done: where its scale and the weight of its messengers come from, and how far the medium departs from a symmetry that the observed weak force keeps to one part in a thousand (10^{-3}). The other is the cascade that would fix the electron’s mass: why the electron weighs what it weighs is, in PIU- Ψ just as in the standard model, an unanswered question. Neither of the two affects what is derived.

What the Pleno resolves, what it reframes and what it leaves open

Open problem	What the Pleno does with it
Two theories that do not fit	derives both from the same medium; gravity is not quantized, the grain prevents the infinities and evolution on the lattice is exactly unitary —it loses no information—: the problem changes its nature
Why gravity is so weak	because the medium is extremely stiff: G does not measure a force, it measures how much the Pleno yields when squeezed, and it yields very little
Constants that are only measured	G and $\hbar$ come out as properties of the medium, and the pure numbers, from its geometry
The rules of quantum theory	the limit on what can be known at once, the Born rule, the ceiling on correlations, spin and the refusal of two electrons to share a place arrive as consequences
Whole charge, confinement, three quarks	charge is the number of turns the phase makes around a knot, and turns come whole; the quarks' thirds only close three at a time
Singularities	the compression ceiling makes them inaccessible, in black holes —whose interior is closed, with a core of finite density— and at the beginning
Dark matter	the same medium with its phase spinning without winding, in proportion $\sqrt{3}\pi$ to ordinary matter
Dark energy and the 10^{123}	the condensate of the medium at rest at the bottom of the well, with $w = -1$ exactly; the gigantic number is the age of the universe in ticks, squared
The Hubble tension and the DESI signal	the same medium read with another model's mold: the measurements are good, the mold is not its own. Both attenuate when measured without that mold; DESI's, on the bare data, falls to 1.3 deviations
The primordial ripples	seeded by the bounce, without inflation
The arrow of time	time is the accumulated change of the medium, counted, and not a stage; its direction rests on the medium's second law, which comes from counting its configurations
Unresolved	the scale of the weak force and the weight of its three messengers; the lepton masses; the link that joins one cycle to the next; why the medium has the density and the grain it has; why there is a Pleno rather than nothing

A wager remains, and it is the one thing neither the algebra nor the notebooks can decide. What PIU- Ψ reproduces of already-validated physics is not what is at stake: those laws are true today, and their certainty is neither lent by the program nor can it be taken away. What is at stake is the route.

But that the route arrives is not a neutral fact about the route. A confirmed law does not need to be proved again because it is reached from another starting point, and it arrives intact; what changes with each arrival is what we know about the starting point. A path that once comes out at a known place may be luck. One that comes out at twenty-seven (27) of them, spread over eight sectors that do not talk to each other, and in many cases with the full number in front, is no longer explained as well by luck, and that is exactly what the coincidence computation measured.

For those arrivals to say nothing about the origin, one of two things would have to hold: the algebra is wrong, or the result was forced. Both can be looked at. The algebra is written out

step by step and three independent notebooks recompute it in full, figure by figure. And forcing a result requires somewhere to force it —a knob, a free coefficient, a margin in which to stow the difference—: F1 has none, and it is the same object across all eight sectors, so a patch that fixed one would wreck the other seven.

And the program also makes predictions of its own:

- The proportions of the cosmos, computed from the geometry of the crystal and a single reading of the clock.
- Dark energy with $w = -1$ exactly, whose relative weight grows as matter dilutes —and, in the end, an expansion rate tending to zero rather than an eternal acceleration—.
- The Hubble tension and the DESI signal as artifacts of the measurement method, which attenuate when measured on observables that do not presuppose the model —DESI's, on the bare data, falls to 1.3 standard deviations—.
- That at very high energies light and the gravitational wave are delayed alike, with a computed energy scale —the square root of twenty ($\sqrt{20}$) times Planck's, seventy-five million times (7.5×10^7) above the bound set by the LHAASO observatory—, and that this delay follow in the sky the pattern of a cube —larger along the four diagonals of its body and smaller along its edges—, with an exact ratio of seven thirds ($7/3$) between the two.
- A core with no singularity for every black hole, with the same gravitating density in all: 1.6545 times the density of the medium.
- A different mass ceiling for each stellar composition.

And above all, the idea that holds them all up: that those scattered laws are, in reality, faces of a single substance.

If the wager proves right, we will have discovered that the entire universe is one thing that compresses and spins, and that the laws we believed separate were always a single one.

All together: a single thing badly understood

The starting fact is uncomfortable: physics, for all its triumphs, is still a puzzle with pieces that do not fit —the very large and the very small described by theories that contradict each other, and nearly ninety-five percent (95%) of the universe made of something we know is there but do not understand—. These are real, acknowledged gaps that have resisted for decades. And against them, PIU- Ψ asks a different question: what if they were not many badly-fitting things, but a single thing badly understood?

Asking it would prove nothing on its own. What counts is how that question is pursued: not with a comfortable tale, but with mathematics that reproduce already-confirmed laws, with high precision and no hand-tuned numbers. This is exactly how science has taken its greatest leaps: someone suspects that separate phenomena are manifestations of something deeper, and then submits it to the test of the data. Newton united the apple and the Moon; Maxwell united electricity, magnetism and light; PIU- Ψ unites the quantum and the cosmic under a single substance, and shows that Newton, Maxwell and Einstein were writing, without knowing it, chapters of the same book.

With the Pleno, several things change category at once. The vacuum stops being nothing and becomes a medium at rest. Space and time stop being the stage and become the extension and the pulse of that medium. The constants stop being data that are measured and become properties that are read, and the Hubble constant stops being a constant and becomes an hour.

The postulates of quantum theory stop being rules and become consequences. Physics loses none of its laws; it gains the reason they are the ones they are.

It is no accident, then, the name the program bears: *Universal Integrity Principle*. It is a *Principle* because everything stands on a single root —six axioms and three quantities— and on the equation that grows out of it, from which the rest is deduced, rather than a catalog of loose rules. It speaks of *Integrity* in its double sense: that of unity (a whole universe, entire, not fragmented into pieces that do not talk to each other) and that of coherence (an edifice that does not contradict itself nor break into infinities). And it is *Universal* because it reserves no corner: it embraces all that exists, from the tiniest particle to the entire cosmos, with a single explanation. The name is the motivation of the program made word: the search for the whole unity of all there is. And the symbol Ψ that appears beside its initials recalls where everything starts: the Pleno, written as the wavefunction of a universe that pulses, at bottom, like a single thing.

23. Twenty-four questions, answered from the Pleno

Each answer stands on its own and uses only what the book has already explained.

1. If atoms are almost empty, why can I not walk through a wall?

Because there is no emptiness to walk through. What is called empty space inside an atom is medium in its state of rest, as full as everything else: an atom is not a handful of little balls separated by nothing, but a configuration of the same continuous material.

And what stops your hand is not a collision between little balls. Your hand and the wall are two regions of knotted Pleno, and the knots that make up their electrons cannot occupy the same place in the same state: this is Wolfgang Pauli's exclusion principle, which in the Pleno comes from the very character of those knots. On top of that comes the electric repulsion between the outer shells of their atoms. That is why, well before anything passes through, what gives way is your hand.

2. Why do things fall?

A mass holds the medium deformed around it, less and less the further out one goes. When two masses are close, those two deformations overlap, and it costs the medium less to sustain one shared deformation than two separate ones. Falling is the way towards the configuration that costs least.

Nothing pulls on anything. The Earth does not tug at the apple: the medium between the two relaxes as they come together, and what relaxes is what we feel as weight.

3. Why is a heavy cart so hard to push, and just as hard to stop?

A cart is knotted Pleno, and moving it means the surrounding medium gives way ahead and recovers behind. While it travels at constant speed that relay runs always at the same rate and asks for nothing new. Accelerating is demanding it faster, and the medium resists the harder the faster it is asked.

Braking changes the rate exactly as accelerating does, and that is why it costs the same. And a heavier cart has more profile to rearrange, so it costs more in both directions. That is inertia: what the medium charges for remaking its profile at a given rate.

4. How can a fridge magnet lift a paperclip, beating the gravity of the whole planet?

Because the two forces come from different properties of the same medium. Magnetism arises from the turning of the phase: on running around a tiny ring of the lattice and coming back

to the starting point, the turning does not come back as it left, and that mismatch is the field. Gravity arises from something else: from the firmness of the medium. And a medium as dense as the Pleno yields very little when a mass is placed in it: that minute yielding is all the gravity there is.

If on the scale of the cosmos it is gravity that prevails, that is for another reason. Electric charges cancel between positive and negative and at large scales almost annul each other; mass only adds and never cancels. That is why it loses against a fridge magnet and wins across the distances between galaxies.

5. What is there between the Earth and the Sun, if they say it is empty?

Medium, in its state of rest. That is what physics calls the vacuum: the lowest-energy configuration the Pleno admits, with a density that is not zero and cannot be, because the cost of annulling it—Klauder’s wall—grows without bound as zero is approached, and the medium never gets there.

It has a density, it has a minimum grain, it carries light and gravity, and it is exactly the same substance the Earth and the Sun are made of. What changes from one place to another is not what it is made of, but how compressed it is.

6. What is light made of, and why can nothing travel faster than it?

Of the same thing as everything else. Each bond of the medium carries a turn of the phase, and light is a twist of those turns that circulates from bond to bond and propagates through the lattice.

That propagation runs at the fastest rate the medium admits changing: one complete turn per cell in the time light takes to cross it. Going faster would mean asking the medium to change faster than it can, and its resistance grows without bound as that rate is approached. The speed of light is not a cap added on: it is the material’s own tempo.

7. What is heat? Why does coffee cool down and never the other way round?

Heat is disorder in the turning of the medium. When the phase hands of all the cells run in step, the medium is cold; when each one turns on its own, it is hot. Temperature measures how much disagreement there is among those turns.

Hot coffee is a region where the turns are especially out of step, surrounded by one where they are less so. That disagreement is passed from cell to cell, and there are vastly more ways of ending up spread out than of staying concentrated. That is why the coffee cools and the room does not suddenly warm: nothing pushes it in that direction, it is that almost every path leads to the spreading.

8. Does time really pass? Why can one not go back?

Time is the change of the medium, counted. Where nothing changes there is no time to measure, and that is why asking how fast time passes is asking at what rate change changes.

And there is no going back for the same reason a coffee does not warm itself up again. The change of the medium is shared out among countless configurations, and there are far more ways of ending up spread out than of ending up concentrated. Going back would require all of them to climb at once toward the improbable arrangement they came from.

9. Why does a clock in a satellite not keep the same time as one on the ground?

Because time is the change of the medium, counted, and the medium does not change at the same rate everywhere. Near a mass it is more compressed, and a more compressed medium rearranges itself more slowly: there everything happens a little more calmly, and a clock—pendulum, quartz

or atomic, it makes no difference— marks fewer seconds. Higher up, where the medium is looser, it marks more.

There is a second effect, and it pulls the other way. The medium has a maximum rate at which it can change, and a clock that moves fast spends a good part of that rate on traveling; what is left over for ticking is less, and it falls behind one standing still.

Both effects are real and are measured daily. In a navigation satellite the one from altitude beats the one from speed, and without correcting the difference the system would be off by kilometers in a single day. What the program adds is not the correction —physics already had that— but where it comes from: both come out of the same equation of the medium, and neither has to be put in by hand.

10. If space were a crystal, would we not notice?

A crystal is noticed when something travels through it with a detail close to the size of its grain. The Pleno's measures some 10^{-35} meters, and a proton —already among the smallest things we know how to point at— is a hundred billion billion times (10^{20}) bigger than that. Everything that can be measured today is enormously longer than the grain, and at that scale the medium behaves as though it were smooth.

There is a geometric reason too. The four tetrahedral bonds, averaged, behave exactly like a sphere for any wave much longer than the grain: the shape of the crystal erases itself, with nothing to be supposed.

The crystal's directions would show only at energies vastly greater than those reached today, and there the program does not shrug: it says how they would show. Light would run a shade slower, and not by the same amount in every direction of the sky, but following the drawing of a cube. And between the direction in which it would slow most and the one in which it would slow least there is an exact ratio, seven thirds ($7/3$). That shape and that ratio are the signature of a diamond lattice.

11. Why is every electron in the universe exactly the same?

Because they all formed in the same window. When the medium crystallized, the rearrangement released a considerable amount of heat, and until it was evacuated the medium sat on a plateau: a stretch in which conditions barely changed.

Particles formed during that plateau, all under the same conditions. And they are configurations of the same medium with the same number of windings: a knot either is or is not, and there is no room for one to come out slightly different from another.

12. If everything is the same substance, why are there so many different kinds of particle?

For the same reason that a single rope can be tied into different knots. What changes from one particle to another is not the material, but the way the medium is knotted: how many turns the phase makes around the knot, and with what pattern it holds itself. And since the turns come whole —half a turn does not close— the possibilities are a few and well separated, not a continuous range. Hence there are types of particle, and not an assortment of particles slightly different from one another.

That is also where the thirds of the quarks come from, which puzzle so many. What the medium demands is not that each knot carry a round charge, but that the set close, and the closing condition is met three at a time. That is why quarks are not found loose, and why the trios they form —two of one kind and one of another— give exactly the charge of the proton and that of the neutron.

How many kinds there are in all, the program does not deliver, and it says so in its place: why the electron weighs what it weighs remains unanswered here, just as it remains unanswered in the standard model.

13. Why are there things that cannot be known at the same time?

How a particle moves is written in the rate at which its phase turns from one point to the next: tight turning, much momentum —momentum is the amount of motion it carries, its mass times its speed—; loose turning, little.

And a wave confined to a small region cannot carry a single rate. To die away outside that region, instead of going on spreading without end, many superposed rates are needed, cancelling one another outside and reinforcing one another inside. The narrower the region, the more rates must be mixed, and the less definite the resulting rate: to confine is to mix rates, and to mix rates is to lose the definite rate.

So in a medium like this the configuration that had at once a narrow position and a sharp motion simply does not exist. It is not that it cannot be measured well: there is no such thing to measure.

14. What exactly happens when something in the quantum world is measured?

Before measuring there is a configuration of the medium spread over a region: a real wave, not a veil of ignorance about where the particle already is. A detector is, in turn, an enormous region of knotted medium, and bringing them into contact ends that spreading: the extended configuration settles into one of the shapes the detector admits, and that is the one recorded.

That one comes out and not another does not have to be added as a separate rule. The medium has a noise of its own —an incessant coming and going at the smallest scale there is—, and that noise is what makes it unpredictable which one falls each time. Chance is not postulated: it is inherited from the material.

And with what probability each one falls is not postulated either. The phase of the medium conserves a flow, that flow is shared out among regions as the water of a river among its branches, and the fraction belonging to a region turns out to be the square of the size of the field there. That is the Born rule, which quantum mechanics states as a postulate. And that same noise pushes the medium towards that sharing and holds it there, in the shortest time the medium admits: that is why no deviation has ever been seen.

15. Why do stars die?

A star holds itself up as long as the pressure of its interior balances its own weight. When its fuel runs out, all it has left to hold on with is the refusal of its electrons to occupy the same state —Pauli's exclusion principle—: where there is one already, no other fits.

That refusal has a ceiling. If the star weighs too much, its electrons would have to move faster than light to keep holding it up, and they cannot. Above a certain mass the star can no longer stop and goes on falling. That limit bears the name of Chandrasekhar, who computed it in 1931. The program computes it with the pieces of the medium itself and gets 1.456 solar masses, against the canonical 1.44.

16. What is inside a black hole?

Medium compressed almost to its ceiling. The Pleno has a compression ceiling, and bringing it close to that ceiling costs an energy that grows without bound, so the collapse does not end in a point of infinite density: it ends in a saturated core, with a finite density.

That density is the same for every black hole, whatever its mass, because it is the saturation density of the medium and does not depend on how much is thrown on top. One of ten solar masses and one of a thousand million have the same heart; what changes is their size. And what that heart weighs is not the medium's whole occupation, but what exceeds the medium at rest: 1.6545 times the density of the medium, equally in all.

17. Is it true that we do not know what 95% of the universe is?

In the standard model, yes: dark matter and dark energy are measured well and accepted without knowing what they are made of. In the Pleno both are the same medium in two different configurations.

Dark energy is the part of the medium that moves in unison, at rest at the bottom of its well, and it is everywhere, including where there is nothing else. And dark matter is medium gathered together, with its mass and its weight, but without the winding—the turns the phase makes around the knot—that anchors ordinary matter to the lattice. That winding is precisely what makes ordinary matter emit and absorb light; without it, the knot weighs and attracts like any other, but it neither shines nor casts a shadow. Which is exactly what astronomers mean when they call it dark.

The proportion between the two kinds of matter comes from the geometry of the crystal, $\sqrt{3}\pi$: there is about five and a half times more dark matter than ordinary (5.44), which is what the satellites measure.

18. This Pleno business —is it not the ether that physics discarded a century ago?

No, and the difference is precisely the one that settled that experiment. The ether sat *inside* space, and so it had a rest of its own: the Earth, moving with respect to it, ought to feel a kind of wind, and light ought to take longer one way than the other. Michelson and Morley measured that difference and found zero.

Here there is no wind to measure. The Pleno is not inside space: it *is* space, and there is no second object to be at rest with respect to. What the program measures—the compression of the medium and the turning of its phase—comes out the same for any observer, however he moves. The null result of that experiment is not something the program has to dodge: it is what it predicts. The remaining differences, one by one, are in “And no, this is not the ether,” in §3.

19. So were Newton, Maxwell and Einstein wrong?

No, and the program does not correct them: it reaches the same place by another door. Newton's law of gravitation comes out of the medium as soon as it is looked at slowly and from far away; the four Maxwell equations come out of following the turning of the phase around the rings of the lattice; the Lorentz factor, by which inertia and energy grow as the speed of light is approached, comes out of F1 itself as soon as a traveling deformation is written, and out of that same computation come relativistic momentum and energy with their exact form. The formulas physics has measured hold exactly as they held: they are true today, and true regardless of why.

What changes is not the content, it is the standing. Things accepted as starting points—that there be a speed limit, that probability be the square, that the electron have spin, that charge come in whole packets—stop being the beginning of the reasoning and become its end. And quantities that could only be measured and put in by hand come to be computed: the gravitational constant, Planck's constant, the proportion between dark and ordinary matter.

It is the same kind of change Maxwell brought when he showed that light was not a separate phenomenon, but electricity and magnetism in motion. No one had to take back a single measurement in optics; what was gained was the reason they were what they were.

20. If the universe is expanding, what is it expanding into? And what was there before the beginning?

Into nowhere, because there is no outside. What we call space is the extension of the medium itself, and expanding is the medium stretching. Asking what it expands into is like asking where the whole universe is: the “where” only makes sense inside it.

And before the beginning there was medium, compressed and climbing its wall, which turned it back before it reached the ceiling. The “before” stops being a problem as soon as time is the change of the medium: as long as there was medium changing, there was time to count.

21. How does the universe begin and how does it end, and why does the program claim that?

The program describes a cycle. Backwards, the medium came compressed and climbing its upper wall; before reaching the ceiling it bounced, and that is the expansion we still see. Forwards, that expansion slows until it stops. That the contents should then fall back, in a great squeeze and another bounce, is the piece the program has open: the equation of the cycle carries that step, but its exact form is not deduced.

It claims this because both ends come out of the same curve, and that curve was not chosen: F1 carries it within. The upper wall is a compression ceiling that makes the singularity impossible—the collapse ends in a saturated core, not in a point—and that is why the beginning is a bounce and not an absolute origin. And what drives the expansion is not the energy the medium keeps at the bottom of the well, but the slope it has left to come down: when the medium reaches the bottom, the slope runs out and the push with it, so the expansion rate tends to zero. There the program parts from the cosmological constant of the standard model, which, not thinning out, would accelerate the expansion for ever.

At both ends, then, the curve says the same: the beginning is not a point of unbounded density, and the end is not an eternal expansion.

22. How can so many different things come out of a single equation?

Because nothing is added along the way. F1 is written with three quantities—the density of the medium, its maximum rate of change and its grain—plus the shape the medium takes on organizing itself. From there each result is obtained by looking at that same equation in a different regime: at small speeds or near that of light, at enormous distances or at the size of the grain, with the configurations aligned or jumbled.

On restricting the view to one regime the equation simplifies, and what remains is, case after case, a formula physics already had. That is why the results cannot be taken separately: they form a tree, and one piece moved to fix one sector would wreck all the others.

23. Why do mathematics describe nature so well?

Nature comes first. Mathematics is the instrument humanity built, century after century and upon what it observed, to understand nature, describe it and anticipate what it would do next. It was honed against the world for millennia, and that is where its accuracy comes from: nature does not follow mathematics, mathematics was made by following nature.

What the program adds is a reason why it serves *so* well. If the universe is a material with a definite shape, its regularities are properties of that shape: proportions, angles, counts of neighbors and of vertices. And describing shapes is precisely what mathematics knows how to do.

That is why the program's numbers look the way they do. The proportion between dark and ordinary matter turns out to be the area of a sphere divided by that of the tetrahedron inscribed in it; the coefficient that fixes how much energy the electromagnetic field holds comes from adding up the six faces of a cell, each counted according to which way it looks. They are not measurements translated into symbols: they are counts made on a figure.

24. If everything is a single substance, am I Pleno too? What makes me different from a stone?

Yes, just like the stone, the air in the room and the light that lets you read this. There are not two kinds of thing, and there is no boundary where one ends and the other begins.

What sets you apart is not what you are made of, but how it is knotted and organized: what configurations the medium takes in you, how they hold one another up and with what precision they copy themselves. The difference between you and a stone is entirely one of structure —and it is all the difference needed.

24. The laws the program reaches

The twenty-seven of the list, one by one: what each law says, whose it is, what it lets us understand, predict or build, and what the program delivers. The mechanism of each is in its own section.

The two constants.

The gravitational constant, G . Newton, 1687; Cavendish measured it in 1798. It says with how much force two masses attract each other. With it we compute the orbits of the planets, predict the tides and place satellites where they belong. The program delivers it as a property of the medium, $G = c^2/\rho_P \ell_P^2$, with the number in front equal to one.

Planck's constant, $\hbar$. Planck, 1900. It says that energy is delivered in steps, and sets the size of the step. With it we understand why atoms are stable, we predict the color of the light each gas emits, and the laser, the LED and the transistor are designed. The program delivers it as the spin of a grain of the medium, $\hbar = \rho_P c \ell_P^4$, also with the number in front equal to one.

Gravity and the shape of space.

Einstein's field equations. Einstein, 1915. They say how matter curves space and time. With them we understand Mercury's orbit and the bending of light passing by the Sun, and without them GPS would err by kilometers a day. The program delivers them whole, with the coefficient $c^4/16\pi G$ complete, and says where its $8\pi = 2 \times 4\pi$ comes from: the 4π is the measure of the sphere that Gauss's theorem reads in the long-range response of the lattice itself, and the 2 is supplied by trace reversal.

The geometry of black holes. Schwarzschild, 1916. It says what space and time are like around a still mass, and where its horizon lies. With it the images of the horizon telescopes are read. The program reproduces it with the correct radius, and adds a closed interior, with no singularity, with a core whose gravitating density is the same in all: 1.6545 times that of the medium. That last is a prediction, with no datum to contrast it with.

The limiting speed and the Lorentz factor. Lorentz, 1904; Einstein gave it its meaning in 1905. It says how much time dilates and distances shorten on approaching the speed of light. With it particle accelerators are designed and the clock of every satellite is corrected. The program delivers it as the resistance curve of the medium itself.

Gravitational waves at the speed of light. Einstein predicted them in 1916; LIGO recorded them for the first time in 2015. The program makes them undulations of the same medium as

light, with the single limiting speed that medium has, so that sharing a speed is not an agreement between two things. Contrast: the wave and the flash of August 2017 arrived equal to within seven parts in ten million billion (7×10^{-16}).

The quantum world.

Schrödinger's equation. Schrödinger, 1926. It says how a particle's wave changes with time. With it we understand the energy steps of an atom, the spectrum of a molecule is predicted before it is made, and the materials of a transistor or the candidates for a drug are computed. The program does not postulate it: written as $\Psi = S e^{i\theta}$, the dynamics of F1 in the slow regime *is* that equation, by an exact transformation.

The uncertainty relation. Heisenberg, 1927. It says that a particle's position and its motion cannot both be made sharp without limit. With it we understand why an atom does not collapse, and the minimum size of any structure is predicted. The program delivers it with its exact floor, half Planck's constant.

The ceiling on correlations. Bell posed it in 1964 and Tsirelson fixed the ceiling in 1980. It says how far the measurements made on two separated particles can agree. With it the randomness of a quantum generator is certified and the security of a quantum key is proved. The program delivers it exactly: $2\sqrt{2} = 2.8284$, and no experiment has gone past it.

The Born rule. Born, 1926. It says that the probability of finding a particle somewhere is the square of the length of its wave function. With it the outcome of any quantum measurement is predicted, which is the computation that sustains all of computational chemistry. The program delivers it as the apportioning of a conserved quantity.

The Dirac equation. Dirac, 1928. It describes the electron at speeds close to that of light, and carries spin inside. With it we understand the fine structure of spectra, and the electron's magnetism is computed to twelve (12) figures. The program delivers its structure by two converging routes, with spin coming out of the medium and not added.

The forces and matter.

Maxwell's equations. Maxwell, 1865. Four equations that join electricity, magnetism and light. With them we understand why a motor turns, we predict how far a signal reaches, and the electrical grid, radio, radar and magnetic resonance imaging are designed. The program delivers them without postulating the field, with the coefficient $8/9$ derived and the photon as the gapless —massless— channel of the phase's turning, with its two polarizations in the two transverse cycles of the lattice's bonds. The equations of the free field come out derived; their coupling to charges has its structure proved and its algebra still to close.

The structure of Yang-Mills. Yang and Mills, 1954. They generalize Maxwell to internal symmetries that do not commute, and are the form of the two nuclear forces. With them what happens in an accelerator is predicted and how the Sun burns is computed. The program delivers their structure from the same geometric construction, and with it color confinement.

Whole charge and the neutrality of matter. A measured fact, with no author. It says that every free charge is an exact multiple of the electron's and that an atom is neutral. With it we understand why matter does not take itself apart by electric repulsion. The program makes it a number of windings of the phase, and neutrality comes out exact: experiment confirms it to one part in 10^{21} .

The exclusion principle. Pauli, 1925. It says that two electrons never occupy the same state. With it the order of the periodic table is understood, and with it the behavior of every material is computed, from a semiconductor to an alloy. The program delivers it from the topology of the knot, and not as an added postulate.

The proton's three quarks. Gell-Mann and Zweig, 1964. They say what a proton is made of and with what charges. With them the whole catalog of particles the accelerators produce is understood. The program delivers the three, their charges in thirds and the asymmetry of two alike and one different, and, with a single input, the proton's size: 0.851 femtometers against 0.841 measured, a 1.19%.

Heat.

Bose-Einstein statistics. Bose and Einstein, 1924. It says how the energy is shared out by particles that can pile up in a single state. With it the spectrum of the cosmic microwave background is predicted and the laser and the traps for ultracold atoms are designed. The program delivers it by counting configurations of the medium itself, bringing in no law of heat.

The Stefan-Boltzmann law. Stefan measured it in 1879 and Boltzmann deduced it in 1884. It says how much a hot body radiates: twice as hot, sixteen (16) times as bright. With it a star's temperature is taken from its brightness and the energy balance of the climate is computed. The program delivers it with its exact coefficient, from the same counting.

Fermi-Dirac statistics. Fermi and Dirac, 1926. It says how the energy is shared out by particles that do not admit two in the same state. With it the electrons of metals and semiconductors are described, and the interior of a white dwarf is computed. The program delivers it from the same counting, with the occupation ceiling coming out of the Dirac equation.

The stars.

The Chandrasekhar limit. Chandrasekhar, 1931. It says the mass above which a spent star no longer holds itself up and caves in. With it the fate of every star in the sky is predicted and the supernovae that measure the universe are calibrated. The program delivers it with its complete coefficient: 1.456 solar masses against 1.44.

The cosmos.

The proportion between dark and ordinary matter. Measured by the satellites, with no explanation in the standard model. The program delivers it as a ratio of areas, a pure number: $\sqrt{3}\pi = 5.4414$ against 5.375 ± 0.077 , agreement at 0.86σ with not one adjusted parameter.

The four densities of the universe. Measured by the Planck satellite. They say how much dark energy, how much matter in total, and how much of it is dark or ordinary. With them the whole history of the cosmos is computed. The program delivers them from the proportion above and a single reading of the clock, and all four fall within 1.2σ .

The Hubble constant. Lemaître in 1927 and Hubble in 1929. It says at what rate the universe expands. With it the distance scale of all astronomy is fixed. The program delivers its whole formula, and it is a product of three pieces: a fixed geometric ratio, the rate of the Planck tick, and what point of its course the medium is at today. The first two the program gives, and in them there is nothing to adjust; the third is read off today's universe, and it is the only thing read. That is why H_0 is not a constant of nature: it is the hour the cosmic clock marks now.

The whole curve of the expansion. The program delivers $H(z)$ —the rate of expansion at each epoch— from that same reading, and contrasts it with the six points of the DESI galaxy map with not one adjusted parameter.

Dark energy that does not dilute. Measured as a density that does not change as the universe expands. With it the acceleration of the expansion is explained. The program delivers it as the phase condensate of the medium, at rest at the bottom of the well, with its $w = -1$ exact and with nothing left over, and vetoes the region where w would be smaller.

The time stretching of supernovae. Predicted by the expansion itself. It says that the brightness of a distant supernova rises and falls more slowly than that of a nearby one. The program delivers it exactly, and the data from the DES supernovae confirm it.

The beginning.

A beginning without a singularity. The program delivers a universe that contracts, turns around at the upper wall of its energy curve before reaching the compression ceiling, and forms matter on the way back. There is no datum to contrast it with: it is a prediction.

25. A note for anyone who wants to check it

None of the answers in this book asks for faith, and the program does not ask to be accepted as truth either: it asks to be checked. The difference matters, because the second can be done and the first cannot.

What makes checking possible is that there is nowhere to hide an error. F1 has no free coefficients, so no result can be readjusted if it comes out crooked: **each number stands exposed just as it comes out.** The corpus is open, with every derivation step by step, every statement labeled by how far it has been proven, and three notebooks that recompute the figures. Anyone wanting to refute it does not need the six hundred and thirty-four (634) pages: one derivation and one number they already know will do.

The program has several pieces and they do not serve the same purpose: this book tells the idea; the website gathers and orders the material; the papers treat individual results. **Technical evaluation —mathematical, physical, scientific— is done on the corpus and the mathematical compendium:** the first carries every derivation step by step with its status label, the second the intermediate algebra and the analysis of units. That is where to go in order to judge, and that is where to point an artificial intelligence asked to review it. A verdict formed on this book is not a verdict on the program.

And today that costs less than ever. A first pass —the algebra, the units, the coherence between sections, whether a cited result says what it is credited with— is within reach of anyone with an afternoon and a tool of the kind already in daily use. That is the invitation, and it goes in the uncomfortable direction: asking that tool to *find the error*, not to confirm the success.

The tool fails in both directions. Asked whether work like this is correct, an artificial intelligence tends to answer what is expected —dismissing it for its resemblance to what is usually wrong—, and asked by the work's own author, it tends to please. Both answers are equally empty. What does return reliable results are bounded questions, the ones with a correct answer regardless of sympathy: do the units of this equation balance? does this step follow from the previous one? does this citation say what it is credited with here? For that the corpus carries a note addressed to reviewers, human and automated, with a single underlying rule: no assessment of the whole before auditing the material that supports it.

After looking, accepting and rejecting are both legitimate answers. Before looking there is only one: I do not know yet.

The symbols that recur

$\Psi = S e^{i\theta}$	the Pleno: the single field —a quantity with a value at every point— of which everything else is a shape
S	<i>modulus</i> , which the text also calls the <i>compression</i> : how compressed the medium is at a point; its square is the density there
θ	<i>phase</i> : which way the medium is turning at that point
ρ_P, ℓ_P, c	the three primary quantities: the density of the medium; its grain, the smallest size of its structure, which falls at the scale physics calls the Planck scale; and the maximum rate of change, the same rate at which light travels
G	Newton's gravitational constant: it sets how strongly two masses attract each other
$\hbar$	Planck's constant: it sets the scale at which the world becomes quantum
$\mathcal{L}_{F1}$	F1, the Lagrangian of the Pleno: the single expression that yields how the medium moves and changes
$S_{\min} = 0.7231$	the floor of the well —the energy curve of the medium—, where the medium rests today; its energy is the curtain, the zero from which everything else is counted
$S_{\max} = 1.4756$	the ceiling: the maximum compression admitted by the crystal the medium organizes into
E_0	the energy scale of the well, its single coefficient: it is $4.2546 \rho_P c^2$, written exactly with π and $\sqrt{6}$
$\xi = 19.69$	curvature of the well at its bottom: how strongly it returns the medium to rest when something pushes it away
x	relative haste: strain rate measured in the unit c/ℓ_P , the maximum rate at which the medium admits a shear
$f_c = 0.6869$	what fraction of the medium moves in unison today: the <i>occupation</i> , one of the two positional readings —where the medium stands along its path— that the program takes from the world
$\Theta_0, N_{\text{tick}}$	the other positional reading, the <i>arc</i> traveled: the time on the cosmic clock; N_{tick} is the age of the universe counted in Planck ticks
Ω	fraction of the content of the cosmos: Ω_{DE} dark energy, Ω_m all matter, Ω_{DM} dark matter, Ω_b ordinary (baryonic) matter
σ	the typical error of a measurement, the unit in which one says how far a value departs from it. In two technical boxes the same letter names something else, and it is said there what it means

Where to go next

All the material of the program is available for download at **piuniversal.com** and on Zenodo, under a Creative Commons license.

PIU-Ψ V5.6 corpus	the complete program, each derivation step by step, with every claim labeled according to how far it is proved (632 pp. in Spanish, 634 in English; 329 numbered equations); its inventory of loose ends: twenty, none load-bearing —five falsifiable, fifteen of enrichment—
Math compendium	the intermediate algebra and the unit analysis; it is the piece that carries the classification claim by claim (150 pp. in Spanish, 151 in English): 342 marks —203 derived, 97 SLD, 37 calibrated, 3 hypothesis, 2 loose end—, so that three in every five are derived
This book	the idea told whole, without proofs, in Spanish and in English
Verification notebooks	the three that recompute and audit the figures: the numerical one, 648 of 648 checks (573 against the corpus and 75 against the compendium, over 617 rows; 60% in the medium's own units, before any yardstick exists); the symbolic one, 312 of 312 (194 rows, 192 with a negative control); and the auditor, 4905 figures audited, none that fails to square

Version 5.6, 30 September 2026. The Spanish and English editions are equivalent: same structure, same equations, same classification result by result. The deposit lives on Zenodo under DOI 10.5281/zenodo.23064146; that of the previous version, V5.5, carries DOI 10.5281/zenodo.22313421.

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