

The Weight of the Unseen

Dark Matter in Questions and Answers
A Companion to The Weight of Possibility

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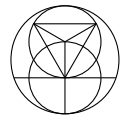
About This Book

This book is a companion to *The Weight of Possibility; Dark Matter as a Vibration of Context*. That book gives an account of the dark matter, the unseen component of the universe whose weight holds galaxies together. This companion says what the account holds, in plain words, for a reader who has no mathematics beyond arithmetic. It is written as questions and answers, grouped into short chapters. Each answer has two parts. The first part says what the account holds. The second part says why the account holds it. The appendix says what the surveys of the coming years will measure, and what the account says they will find.

The account rests on a second book, *The Gravitational Passage*, which derives the law of gravitation and the shape of space and time, and which this companion calls the Passage. The Passage settles the setting in which the dark matter lives: the law of gravity, the constant that drives the expansion of the universe apart, the six small dimensions of the internal space, too small to see, and the turn between one epoch of the universe and the next. *The Weight of Possibility* gives the account of what the dark matter is, with its derivations. A third document, a dated record, fixes the account's predictions at a date, so that later measurements can test them. This companion says nothing that those three do not say. Why the constant that drives the expansion has the value it has is told, for the same reader, in *The View from Inside*; I use the results of The View from Inside and do not retell the reason for the value.

One idea runs through every chapter. The world has three settings in which anything is measured: space, time and possibility. Each setting can be bent out of its plain shape, and three things in nature do the bending. Gravitation bends space. The constant that drives the expansion, often called dark energy, bends time. The dark matter bends possibility. Chapter 2 explains this idea, and every later chapter uses it.

Numbers are few, and each comes with its plain meaning. Where the account names a physical quantity, this companion names it in words first, and gives the symbol only where a reader may meet it elsewhere.



Chapter 1

What Is Seen

The Evidence for the Dark Matter, and What It Shows

1.1 **What do astronomers actually observe?**

What the account holds. The universe contains matter that has never been seen to do anything except pull by its weight. Galaxies spin faster than their visible stars and gas could hold together, and something unseen holds them. Clusters of galaxies bend the light of more distant galaxies more strongly than their visible matter can. The oldest light in the universe, the microwave background, was released early in the present epoch (the present cycle of the universe, which began at what is called the Big Bang) and still reaches us from every direction. It carries a pattern that this unseen matter set before any star had formed.

Why. Each of these effects is an effect of weight. The unseen matter has energy, so it pulls, and its pull shows in the bending of light, in the spinning of galaxies and in the pattern of the oldest light. It was first inferred in 1933, from the speeds of the galaxies in the Coma cluster, which move too fast for the visible galaxies to hold together. The outer parts of the Andromeda galaxy turn about as fast as its inner parts, so the galaxy's mass keeps growing far from its center. The bending of light weighs the unseen matter without any assumption about how the matter moves. These observations are the facts the account has to explain.

1.2 **Has the dark matter been seen to do anything else?**

What the account holds. No. The dark matter has not been seen to scatter off anything, to destroy itself, or to decay. When two clusters of galaxies collide, their hot gas crashes together, slows and heats up, while the dark matter passes through without any measurable collision. In one such collision, the mass mapped by the bending of light lies with the galaxies and apart from the hot gas, which holds most of the ordinary matter.

Why. Ordinary matter collides, glows and absorbs light. The dark matter does none of these. Every piece of evidence for it is evidence of its weight alone, and none of the evidence shows what it is made of.

1.3 **How much dark matter is there?**

What the account holds. By mass, there is about 5.4 times as much dark matter as ordinary matter. The ordinary matter is everything made of atoms: stars, gas, planets and people. The proportion between the two is the same everywhere the microwave background can measure it.

Why. The pattern in the oldest light shows no difference between the dark matter and the ordinary matter from place to place, to within about one percent. So wherever we look, the dark matter and the ordinary matter stand in the same proportion.

1.4 **Has the amount of dark matter changed over time?**

What the account holds. No. The amount of dark matter has not changed since the microwave background was released, early in the history of the present universe.

Why. A component that decayed into anything unseen would have changed the expansion of the universe since then. Measurements of the expansion rule out such a decay for any lifetime shorter than about a hundred and sixty billion years. A decay into anything that we can see would be ruled out far more tightly.

1.5 **Could more ordinary matter, too faint to see, stand in for the dark matter?**

What the account holds. No. The ordinary matter and the dark matter left different marks on the oldest light, and both marks are there.

Why. In the early universe, the ordinary matter moved together with the radiation, and the two oscillated together as sound waves. The dark matter took no part in those sound waves and only pulled. The oldest light measures the density of the ordinary matter and the density of the dark matter separately, from the heights of the peaks in its pattern (its warm and cool spots come in favored sizes, as a drum sounds favored notes, and how strongly each size shows is a peak), and faint ordinary matter counts in the first of these, not the second.

1.6 **How did the dark matter shape the galaxies?**

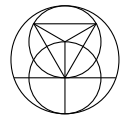
What the account holds. The dark matter built the scaffolding on which the galaxies formed. The small departures from evenness with which the present epoch began grew first in the dark matter, and the ordinary matter later gathered in the wells that the dark matter had made.

Why. In the early universe, the ordinary matter oscillated together with the radiation and could not gather into clumps. The dark matter did not oscillate with them, so the departures grew first in the dark matter. Structure forms in the wells of the dark matter, and the ordinary matter that fell into those wells formed the galaxies we see.

1.7 **Is the dark matter a mistake in our law of gravity?**

What the account holds. No. On this account, the dark matter is real energy, located where it pulls, and it pulls by the ordinary law of gravity. In the account, the law of gravity is exactly as Einstein's general relativity gives it, at every scale from the laboratory to the largest structures, and down to the smallest scale at which space can be described as smooth.

Why. The Passage derives the law of gravity and holds that its form is exact down to the smallest scale at which space can be described as smooth, the Planck scale. The dark matter has energy, so it pulls, as all energy does under that law. Changing the law of gravity instead still leaves clusters of galaxies short of mass, and without dark matter a changed law predicts a lower third peak in the pattern of the oldest light than the one measured.



Chapter 2

Three Distortions of Context

Gravitation, Dark Energy and Dark Matter as One Triple

This chapter sets out the idea on which the rest of the book depends. The world has three settings, three things that bend them, and three edges.

2.1 **What is a context, and what is a content?**

What the account holds. Every physical measurement involves six kinds of measure, in two rows of three. The contents are pattern, force and probability. The contexts are space, time and possibility. Each content is measured in its own context: pattern in space, force in time, and probability in possibility. So the six fall into three columns, each pairing a content with its context: pattern with space, force with time, and probability with possibility. A content is what a measurement registers. A context is where the measurement registers it.

Why. Every measurement is a comparison: it sets one thing beside another, a length beside a ruler, a reading beside a standard. The Passage sets out these six kinds of measure and shows that every measurement uses them. A map records a pattern laid out in space; a push is a force acting over a time; a forecast of a seventy percent chance of rain is a probability spread over what could happen. In the Passage's words, what is measured is con-

tent, and the arena in which it is measured is context. *Comparison; The Necessary Basis* and *Two Theories, One World* tell this part of the story at length, for the same reader.

2.2 **What does it mean to distort a context?**

What the account holds. A context can be distorted: its shape can depart from the shape it has when nothing distorts it. There are three contexts, so there are three distortions. Gravitation distorts space. The constant that drives the expansion of the universe, the cosmological constant, distorts time. The dark matter distorts possibility.

Why. Gravitation curves space around matter; bound structures such as planets and galaxies form in that curvature, and light follows it. That distortion is local: it is where the matter is, and in proportion to it. The cosmological constant is the same at every place and at every time, and it increases the distance between every pair of distant places. That distortion is in the course of the whole universe over time. The dark matter is a vibration of the six small internal dimensions, which are, in plain mathematics, a space of possibilities. That distortion is of what could occur.

2.3 **In what sense are the six internal dimensions a space of possibility?**

What the account holds. The six internal dimensions, small dimensions beyond the four of space and time and too small to see, have exactly the shape of a space of possibilities. Four of them have the shape of the possible states of a system with three alternatives. The other two have the shape of the possible states of a system with two alternatives. The Passage calls the internal space "a space of possibility in the plain mathematical sense", and in the account it is the setting of what could be found.

Why. Each possible state of a system with two alternatives is one point of a globe: the north pole is wholly the one alternative, the south pole wholly the other, and the points between are the states between them. In mathematics, the possible states of a system with three alternatives form a space of the same kind with four dimensions, called the complex project-

ive plane. The possible states of a system with two alternatives form a sphere. The Passage derives that the six internal dimensions have exactly the shape of the plane and the sphere taken together, with a whole sphere at every point of the plane, and that the sphere is held at a radius of one Planck length (the smallest length built from the constants of gravity, quantum theory and light, about a hundred billion billion times smaller than a proton) and the plane at about two and a half Planck lengths, the scale that bounds every comparison made from a place. So the internal space is, at once, part of the geometry of the world and the space of what could occur.

2.4 **Why speak of possibility at all in a book about physics?**

What the account holds. Because, on this account, the dark matter is a bending of possibility, and a physics of space and time alone has no place for it. On the account's view, the idea of a universe has three sides. One side is what exists, laid out in space. One side is what happens, the interaction of things in time. One side is what could come to be, which the Passage calls creation. Physics reports in the manner of the first side: it describes, locates and specifies.

Why. The Passage holds that creation is not a single past event but the standing ground from which something new can come to be. The dark matter is a distortion of possibility, and possibility belongs to creation, the third side. It is a distortion of what could occur, and so it is the one part of the world's weight that belongs to possibility rather than to space or to time.

2.5 **What are the three edges of reality?**

What the account holds. Reality, as far as anything inside it can compare, has three edges. The horizon bounds how far we can see. The Planck scale bounds how sharply anything can be located, and the Planck scale is not a

least length of space. The turn between epochs bounds where our history begins. Each edge belongs to one of the three contexts: the horizon to space, the turn to time, and the Planck scale to possibility.

Why. The horizon is the boundary of the space within which anything can ever be compared with us. The turn is the limit of the time of every history: each history of an epoch runs back toward it and does not pass it. The Planck scale is where the internal dimensions of possibility are held, and it is the bound of every comparison made from a place. So each edge is the limit of one context.

2.6 **How does each distortion meet its edge?**

What the account holds. Each distortion meets the edge of its own context. The dark matter is held exactly at the Planck scale, the edge of possibility. The cosmological constant is fixed by the time elapsed since the turn, the edge of time. Gravitation acts within the horizon, the edge of space.

Why. The six internal dimensions are held at the Planck scale, and the dark matter is a vibration of them, so it is held at that edge. The Passage fixes the cosmological constant through the distance light has traveled since the turn, so it is tied to that edge. Gravitation gathers matter within the horizon; in an epoch whose matter has thinned away, the horizon bounds a geometry with almost no gravitation, at its most symmetric.

2.7 **How do the three distortions differ?**

What the account holds. The three are distinct, inseparable and not interchangeable.

Why. They are distinct because each behaves differently. The cosmological constant is uniform and never clumps. Gravitation is local and follows matter. The dark matter clumps, and never loses its energy or collides.

They are inseparable because all three appear together in the one equation that governs the expansion of the universe. In a flat universe (one in which light that starts out parallel stays parallel) the shares of the

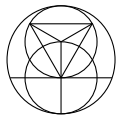
cosmological constant, of the matter and of the radiation add up to the whole, and gravitation is the equation itself. The dark matter, which acts only by its weight, cannot be registered apart from gravitation.

They are not interchangeable because none can do another's work. No amount of the cosmological constant makes a halo of dark matter around a galaxy. No amount of dark matter speeds up the expansion of the universe. Gravitation is the response of space to matter, and it is not an item in the budget of the universe at all.

2.8 **Do the three distortions follow one another in a cycle?**

What the account holds. Yes. Possibility precedes time, time precedes space, and space precedes possibility again.

Why. At the end of an epoch, inside black holes, the internal dimensions of possibility are released from the Planck scale, and the turn follows. After the turn, the cosmological constant, fixed by the time since the turn, sets the size of the horizon that the epoch has once its matter has thinned away. Within that horizon, gravitation gathers matter into black holes, whose interiors reach the Planck scale again.



Chapter 3

What the Dark Matter Is

A Vibration of Context, Not an Item of Content

3.1 **Is the dark matter made of particles?**

What the account holds. The dark matter is made of gyrations: a gyration is a conserved excitation of the six held internal dimensions, a lasting vibration of their geometry. In theories with extra dimensions, a vibration of this kind is called a particle. In this account's sense, a gyration is not a particle: a particle is an item of content, something a measurement registers, and on this account the dark matter is not content. The dark matter is a vibration of the six small internal dimensions. Sound in a crystal comes in small units of vibration, called phonons, and a phonon is a vibration of the crystal, not an extra thing inside it. A gyration is a vibration of the internal geometry in the same way: a vibration of the held space, not an extra thing inside it.

Why. A vibration of the internal space is a distortion of a context, not an item of content. It has energy, so it has weight. It is not content, so nothing that registers content registers it. What is observed of the dark matter is exactly weight, and nothing else. The internal space is held at one size, as a crystal holds its shape, and that is why each of its vibrations has a definite energy, as each vibration of a crystal has. Ordinary space is not held in that way, and gravitation, the bending of ordinary space, does not come in units: gravitation is not quantized.

3.2 **Then what is it, physically?**

What the account holds. Physically, a gyration is a heavy vibration of the geometry of the six held internal dimensions, of a kind long studied in theories with extra dimensions. Each gyration has a mass of about the Planck mass, which is about ten billion billion times the mass of a proton. In the simplest calculation the lightest lasting vibrations have about one and two fifths Planck masses, and the first correction brings them to about six tenths. Three states of vibration share the lowest mass in every calculation made so far, one of spin two and two of spin one.

Why. The account's claim concerns what the vibration is: it is a vibration of context, and not an item of content. The account does not claim that the vibration differs physically from the vibrations of extra dimensions that physicists already study. The internal dimensions are held at about the Planck length, so their vibrations carry about the Planck mass. Whichever of the three candidates is lightest, it cannot decay, and the account's counts hold for it, with its own mass.

3.3 **Why is the dark matter dark?**

What the account holds. The dark matter is dark not because it is hidden behind something, but because it is not the kind of thing that light or any detector registers.

Why. Light, detectors and all instruments register content. The dark matter is a vibration of the internal geometry, a context, so none of them registers it. It shows itself only by its weight.

3.4 **Is the dark matter made of small black holes, or of what is left when they evaporate?**

What the account holds. No. The dark matter is a vibration of the internal geometry, not a black hole and not the remnant of one.

Why. Black holes of the Planck mass, and the remnants left when black holes evaporate down to that mass, have been proposed as the dark matter. The account shares one feature with those proposals: there is no lower state for the dark matter to fall into, so it lasts. The account differs in what the dark matter is, a vibration of the internal geometry, and in where it comes from: it is made at the turn between epochs, and is not carried through it. A gyration is a level of vibration of the internal geometry, with a definite energy; it is not a collapsed region of space.

3.5 **Does the dark matter collide, with ordinary matter or with itself?**

What the account holds. No. The dark matter clumps, and it never loses its energy or collides.

Why. Colliding clusters of galaxies show the dark matter passing through while the hot gas collides. In this account the dark matter cannot collide with ordinary matter, because it acts on ordinary matter only by its weight. The gyrations carry a charge of the forces that belong to the symmetries of the internal sphere; the account holds only if those forces stay bound at the Planck scale and never reach across ordinary space, so that the gyrations exert no force on one another beyond their weight. By their weight alone, gyrations scatter off one another at least forty-five powers of ten more weakly than the most sensitive bound that colliding clusters of galaxies set. Two gyrations can, in principle, destroy each other, but by the account's computation, near the Sun each gyration would meet such an end only about once in a span of time so long that it is no way out at all.

3.6 **Is this the same as the cold dark matter of standard cosmology?**

What the account holds. In everything astronomers can see, yes. The dark matter of this account behaves exactly like the cold dark matter of the standard picture of cosmology: it clumps under its own weight, builds the scaffolding on which galaxies form, and passes through everything. What the account changes is not how the dark matter behaves, but what it is.

Why. A gyration of about the Planck mass has no motion from heat that could matter, so the dark matter is perfectly cold. A perfectly cold matter that does not collide meets every present bound that separates cold dark matter from warmer or wavier alternatives.

3.7 **Does this account overturn the standard picture of cosmology?**

What the account holds. No. The account keeps the two dark ingredients of the standard picture of cosmology, a constant that drives the expansion apart and a cold matter that only pulls, and says what each of them is. The cosmological constant is the constant term of the geometry of space and time. The dark matter is a vibration of the internal dimensions.

Why. The standard picture of cosmology needs a constant that drives the expansion apart and a cold matter that only pulls. The Passage gives the first, and *The Weight of Possibility* gives the second.

3.8 **Is the dark matter real, or an error in how we describe the visible matter?**

What the account holds. The dark matter is real energy, located where it pulls. It is not an error in our description of gravity or in our count of the visible matter.

Why. The dark matter has energy, and all energy pulls. Its pull is measured in galaxies, in clusters and in the oldest light, and in each case it is where the extra weight is.

3.9 **Is the dark matter still being made today?**

What the account holds. No. On this account, the dark matter is made only at the turn between one epoch of the universe and the next.

Why. A component that gives energy to nothing after it is made, and takes energy from nothing, can have exchanged energy with the rest of the world only where conditions were extreme enough. The Passage describes one such place, seen from two sides: the deep interior of a black hole and the origin of an epoch. The deep interior of a black hole and the origin of

an epoch are one transition, the turn. After the turn, the one process that could still make dark matter is the making of gyrations in pairs by an extremely hot gas through gravity alone. The account holds only if the new epoch never becomes hot enough for that.

3.10 **Could a particle collider set off a fire that turns ordinary matter into dark matter?**

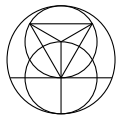
What the account holds. No. A "dark fire", in which ordinary matter is turned into dark matter atom by atom, each conversion setting off the next, cannot happen on this account, in a collider, in a star or anywhere else within an epoch.

Why. The first reason is the kind of thing the dark matter is. It is a vibration of the space of possibility, not an item of content, and it couples to content through gravity alone. Within an epoch the one way content can make it is the making of gyrations in pairs through gravity alone, which needs a gas hotter than about one thirtieth of the mass of a gyration (3.9); no other process within an epoch turns an item of content into a vibration of possibility.

The second reason is energy. One gyration holds the energy of the mass of about ten billion billion protons. Even when the largest particle collider collides two heavy nuclei head on, it brings together about a million times the energy of a proton's mass, trillions of times too little to make one gyration. The most energetic particles that reach the Earth from space each carry less than a ten-millionth of the energy one gyration holds. Gravity alone can make gyrations in pairs only in a gas hotter than about one thirtieth of the mass of a gyration, and nothing in our epoch has been that hot.

The third reason is the link a fire needs. Each conversion would have to pass something on to the next atom, and gyrations act on ordinary matter only by their weight, which at the scale of atoms is far too weak to pass anything on.

The account makes no claim about which particles exist, so this answer concerns the dark matter it describes, which is the dark matter such a fire would have to make.



Chapter 4

Why It Lasts

The Three Exits, and Why Each Is Closed

4.1 **Why should anything last forever?**

What the account holds. A state lasts when every way out of it is closed. The dark matter has three possible ways out: into the content of the world, into waves of the geometry, and into evaporation. The account holds that all three are closed.

Why. A way out is a lower state that the state can reach through some link that exists. The Passage already contains one state that lasts for this reason: the lowest motion of the internal space, which "cannot radiate or dissipate" because it is already the lowest state. The answers that follow take each of the dark matter's three ways out in turn.

4.2 **Why can the dark matter not turn into ordinary matter?**

What the account holds. A vibration of the geometry of possibility and an item of actual content are not interchangeable. Such a vibration does not become an item of actual content by any process within an epoch.

Why. A vibration of the geometry of possibility and a thing are two different kinds. The geometry itself re-forms only where the comparison re-forms, at the turn. So within an epoch, no process turns such a vibration into a thing.

4.3 **Why can the dark matter not turn into gravitational waves?**

What the account holds. The laws of the internal geometry have a symmetry that protects the dark matter. The symmetry swaps each point of the sphere with its opposite point. Every vibration of the internal geometry either keeps its sign under that swap or changes its sign. The gravitational waves of ordinary space keep their sign. The dark matter is the lightest vibration that changes its sign, so it has nothing to decay into.

Why. The laws of the geometry contain the geometry alone, and they are unchanged when each point of the sphere is swapped with its opposite. So a single vibration that changes sign cannot pass its energy to waves that keep their sign. The lightest vibration that changes sign has no lighter one of its kind to fall to, so it cannot decay at all. A protecting symmetry of this kind is already used in theories with extra dimensions; here the protecting symmetry is the swap of opposite points of a sphere.

4.4 **Why must that symmetry be exact?**

What the account holds. The account holds that the swap of opposite points is exact, because two arrangements of the whole internal geometry that differ only by that swap are one and the same arrangement.

Why. Physicists expect gravity at its smallest scale to break any symmetry that is not exact. A gyration of about the Planck mass is protected only by an exact symmetry, because the effects that break inexact symmetries are strongest at that mass. The swap of opposite points is a change in how the internal geometry is described. No comparison can tell apart two arrangements of the whole geometry that differ only by that change, so they are one arrangement. That the two arrangements are one arrangement is what it means for the swap of opposite points to be an exact symmetry, and no effect can break the symmetry of the swap. The sameness holds for whole arrangements, not for single points: if each point of the sphere were itself the same as its opposite point, the sphere would become a different space,

on which the dark matter could not exist. A single gyration then carries a sign that no nearby comparison can detect, and in a closed universe the gyrations must come in an even number.

4.5 **Why can the dark matter not evaporate?**

What the account holds. A vibration at the Planck scale has no lower level of its kind into which to evaporate.

Why. The next scale at which evaporation could act lies some thirty powers of ten away. The internal space has a floor, the lowest state of its kind, and there is nothing below it. Remnants of black holes at the Planck mass have been held stable for the same reason.

4.6 **What about the swelling and shrinking of the internal space?**

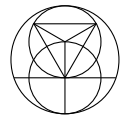
What the account holds. The swelling and shrinking of the internal space as a whole does not last. The vibrations of that kind, which keep their sign under the swap, decay almost at once into gravitational waves. So the lasting dark matter is the lightest vibration that changes its sign, and that alone.

Why. Nothing protects the swelling and shrinking vibrations. They are linked to pairs of gravitational waves, and no symmetry forbids that link. For a link of natural strength, the lowest such vibration decays in a tiny fraction of a second.

4.7 **Does the dark matter ever decay at all?**

What the account holds. No. The dark matter does not decay, so it thins out as the universe expands exactly as ordinary matter does. The proportion between the two is therefore the same today as when the microwave background was released.

Why. All three ways out are closed, so no gyration has anywhere to go.



Chapter 5

How Much There Is

The Proportion of Dark Matter to Ordinary Matter

5.1 **What does the account predict about the amount of dark matter?**

What the account holds. The account predicts the proportion of dark matter to ordinary matter as a pure number: six less two divided by pi. Two divided by pi is about 0.64, so the proportion is about 5.36. In words, there are about 5.36 kilograms of dark matter for every kilogram of ordinary matter.

Why. The proportion is written $6 - 2/\pi$. The six is the count for the dark matter. The count for the ordinary matter is one, so the proportion is a count of six against a count of one, less a share. The two divided by pi is a share removed from the six by the bending of the internal space. The answers that follow explain each part.

5.2 **Why does the account count kinds of shape, and not carriers of energy?**

What the account holds. A measurement counts independent kinds of shape, which mathematicians call classes, and not holders of energy. The dark matter is counted by six independent kinds, and the ordinary matter by one.

Why. The Passage already counts in this way: it counts the channels through which a measurement registers by the independent kinds of the four internal dimensions shaped by three alternatives, and it finds three.

In mathematics, a space has a definite number of independent kinds of shape, the basic pieces from which it can be built. The surface of a ball can be built from two: a single point, and a disc whose whole rim is drawn together to that point, like a drawstring bag pulled shut. When two shapes are taken together, every piece of one pairs with every piece of the other, so the counts multiply. The internal space has six. The four dimensions shaped by three alternatives have three such kinds, and the sphere has two, and three times two is six. The dark matter is a vibration of the whole internal space, and the account holds that it ranges over all six, both kinds of the sphere included: it is not content, so nothing ties it to the row of content alone. That a measurement counts what it registers by kinds is the account's own principle. The six kinds of shape are a different count from the six dimensions: four and two dimensions make six by adding, while three and two kinds make six by multiplying.

5.3 **Why does the ordinary matter count as one?**

What the account holds. The ordinary matter is registered in the visible space, meaning the three large dimensions of space, within the horizon of what has been compared with us so far, and the region within that horizon counts as one.

Why. A measurement reaches the visible space only within its horizon, and that region is a ball. A ball has one independent kind. Within the horizon, no comparison can tell that ball apart from a ball in a space without end, so for a measurement the visible space counts as one, whatever it is beyond the horizon.

5.4 **Where does the two divided by pi come from?**

What the account holds. The internal space is bent, and the count of six is reduced by a share of that bending. The account calls that share the abiding: to abide is to hold fast, and the abiding is the part of the bending that holds fast as a term of its own and is deducted from the count. The bend-

ing that abides is the bending of the four dimensions shaped by three alternatives, and not the bending of the sphere. That share is two divided by pi.

Why. The visible space is flat, so the one kind counted there carries no bending and is counted whole. Each internal direction is bent at the Planck scale, and the count registered there is reduced by its bending. The share comes from the Passage's count of a horizon: a bending of a given strength sets a horizon, and the share is three of that horizon's degrees of freedom (the independent ways in which it holds its energy) among all of them. For the four dimensions shaped by three alternatives that count is one and a half times pi, which gives two divided by pi; for the sphere it is three times pi, which gives one divided by pi; for the whole internal space it is pi, which gives three divided by pi. The Passage's rule for the cosmological constant has the same form: a whole number fixed by the structure, eight, less a share of the bending of the internal space, and its share is three divided by pi. *The View from Inside* tells how that rule is reached. In the account, a count that already includes the sphere's own kinds is not reduced again by the sphere's bending. The proportion's count includes the sphere's two kinds, so only the other factor's bending abides, and the share is two divided by pi. The Passage's count includes one kind of the sphere, not both, so there the whole internal bending abides, and the share is three divided by pi. One statement gives both numbers.

5.5 **How is the rule for the dark matter related to the rule for dark energy?**

What the account holds. Dark energy (the energy of empty space, which physicists call the cosmological constant) and dark matter are two distortions of two different contexts: dark energy distorts time, and the dark matter distorts possibility. They are the only two distortions that carry a share of their own in the budget of the universe. They are fixed by two different rules of the same present measurement, and the two rules share one number.

Why. The share removed from the count by the bending of the internal space appears in exactly two places: in the cosmological constant and in the dark matter. It does not appear in the ordinary matter, which is content. The shared number is how tightly the internal dimensions are bent, which the Passage sets at exactly the Planck scale. The rule for dark energy fixes the share of matter in the universe at 31.1 percent; how that rule is reached, and why the energy of empty space has the value it has, are told for this reader in *The View from Inside*.

5.6 **Why is the proportion the same everywhere and at every time?**

What the account holds. The proportion has been the same since early in the present epoch, and it is the same everywhere.

Why. The ordinary matter and the dark matter are each conserved in number. Since the ordinary matter cooled, early in the present epoch, both have thinned out in the same way as the universe expanded, so their proportion has not changed. The pattern of the oldest light carries no difference between the two from place to place.

5.7 **Does the turn that begins our epoch have to know the mass of the proton?**

What the account holds. No. The account fixes the proportion by what a present measurement registers, and not by a mechanism at the turn.

Why. If the proportion were set at the turn, the turn would have to tie a gyration of the Planck mass to the mass of the proton, across nineteen powers of ten. The Passage fixes the cosmological constant in the way the account fixes the proportion: by what a measurement made inside the universe registers today, with the reconstructed history carrying that value back to every earlier time. The account fixes the proportion of dark matter to ordinary matter by the same kind of rule, acting at the measurement. So the turn makes the gyrations, and the proportion that a measurement finds is fixed by the rule. The rule ties neither the number nor the mass of the gyrations to the proton.

5.8 **Does the rule fix how much dark matter there is?**

What the account holds. The rule fixes the dark matter relative to the ordinary matter. The amount of ordinary matter, about six protons and neutrons for every ten billion particles of light, is a fact of content, which in the account is taken as measured.

Why. Other accounts of very heavy dark matter set its amount by the details of the early universe, such as its temperature. This account fixes the amount of dark matter relative to the ordinary matter, which no other account of very heavy dark matter does.

5.9 **How is the energy of the universe divided?**

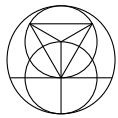
What the account holds. About seven tenths of the energy of the universe is the cosmological constant. About a quarter is the dark matter. Only about one twentieth is ordinary matter. So most of the energy of the universe is a distortion of the setting, not things in it.

Why. The Passage gives the share of matter as 0.311. The account divides that share between the dark matter and the ordinary matter, by its proportion, with a small part left for the lightest neutrinos (very light particles that pass through almost everything).

5.10 **How many gyrations are there?**

What the account holds. There is about one gyration for every one and a half to three and two fifths billion billion protons and neutrons. Near the Sun, there is about one gyration in every few tens of thousands of cubic kilometers.

Why. Each gyration has about ten billion billion times the mass of a proton, so very few gyrations carry about 5.4 times the mass of all the ordinary matter. In this account the dark particles are very few against the ordinary particles, the opposite of accounts in which dark and ordinary particles are about equal in number.



Chapter 6

The Cycle of Epochs

The Turn, and What It Means for the Dark Matter

6.1 **What is the turn?**

What the account holds. The turn is the transition from one epoch of the universe to the next. The collapse inside the black holes of one epoch and the beginning of the next epoch are one transition, approached from its two sides.

Why. The Passage holds that every bound structure of an epoch ends in black holes, that the interiors of the black holes are one at their end, and that the space outside empties. When nothing holds the internal dimensions small any longer, the large and the small dimensions re-form together, and a new epoch begins. No comparison registers the turn itself as an event.

6.2 **What came before the Big Bang?**

What the account holds. On this account, the collapse of the black holes of the previous epoch came before the Big Bang. The cycle of epochs has no first epoch.

Why. The beginning that each epoch's history finds, its Big Bang, is the turn, approached by the collapse of the previous epoch's black holes. Tracing our history back, we meet a limit we cannot pass, and it appears to us as a beginning at a definite time. No measurement made in our epoch can register the turn itself, so our history finds it only as its beginning.

6.3 **Was the Big Bang a creation from nothing?**

What the account holds. No. On the Passage's account, the beginning of an epoch is neither a creation from nothing, nor a fluctuation in an empty space that already existed, nor a point at which the equations break down.

Why. The beginning is a transition in a cycle: the geometry re-forms its large dimensions, because the conditions that dissolved the old ones also make a new one necessary.

6.4 **Does the dark matter of one epoch pass into the next?**

What the account holds. No. Each epoch's dark matter is made at its own turn. No gyration passes from one epoch into the next as a gyration.

Why. Every gyration, like all other matter, either ends inside a black hole or is carried away alone. In both cases the internal space of which it is a vibration comes undone. The Passage holds that no count of anything passes the turn. What returns is the law that protects the dark matter: the new epoch has the same internal shape, the same lasting vibrations and the same symmetry.

6.5 **Why does the dark matter not pile up, epoch after epoch?**

What the account holds. Because none of the dark matter passes from one epoch to the next, each epoch holds only the dark matter that its own turn makes.

Why. If every gyration passed into the next epoch, their number would grow without limit, since the cycle has no first epoch. If only some passed, a count would pass the turn, which the Passage excludes. So each epoch starts afresh, and the proportion registered in an epoch counts all the dark matter present in it. Conformal cyclic cosmology, Roger Penrose's account of a universe that passes through a sequence of epochs, also has dark matter of the Planck mass made between epochs; in that account the dark matter must decay so that it does not pile up. In this account, no decay is needed.

6.6 **Does the account need a period of rapid early expansion, often called inflation?**

What the account holds. No. In the account, no inflation is needed to explain why the sky looks the same in every direction and why space is flat.

Why. Regions that no signal has connected are alike because they come from one domain at the turn, not because a signal passed between them. Space is flat because no length of the old epoch passes the turn. The Passage excludes an inflation long enough to stretch the scales seen today from inside the early horizon to beyond it, and says that a shorter inflation is neither required nor excluded. Excluding a long inflation matters for the dark matter, because after a long inflation of the usual kind, dark matter of about the Planck mass could not have been made in the measured amount. In this account the dark matter is made at the turn instead.

6.7 **What does the account require of the turn?**

What the account holds. The account requires three things of the turn. First, the hot gas of the new epoch must never be hotter than about one thirtieth of the mass of a gyration; or, if the energy of the turn reached the gas gradually, the stage that released it must end below about one hundredth of that mass. Second, the gravitational waves into which the settling of the internal space sends its energy must stay below about three percent of the energy of the radiation of the content: either the internal space settles very gently, or a later stage of the content releases enough radiation to outweigh the waves. Third, the internal space must re-form slowly and gently, so that it makes far fewer gyrations than a sudden re-forming would.

Why. Each requirement keeps the amount of dark matter and of radiation from the turn within what is measured. A hotter gas would make too many gyrations by gravity alone. A rougher settling would leave more gravitational waves than the oldest light allows. A sudden re-forming would make far too many gyrations.

Appendix

What the Coming Surveys Will Measure

What Each Measurement Will Find, on This Account

A.1 **What does the account predict?**

What the account holds. The account makes one numerical prediction, the proportion of dark matter to ordinary matter, about 5.36, and six predictions of kind.

Why. The first four predictions of kind follow from what the dark matter is in the account: it acts only by its weight; it does not decay; it is perfectly cold; and it is made of gyrations of about the Planck mass. The fifth follows from how the proportion is counted: no closed path around the universe, anywhere in space, is shorter than the width of the horizon. The sixth follows from the rule acting wherever a measurement reaches: the dark matter carries no separate pattern of the early departures from place to place. The dated record fixes the first five at its date, the fifth for our location; *The Weight of Possibility* states the fifth for every location, and states the sixth.

A.2 **Why does a dated record matter?**

What the account holds. The predictions are fixed in a record at the date of 10 October 2026, and the record is not revised. Agreement with measurements made before that date shows that the account is consistent with them, not that it foresaw them. The real test is against measurements made after the date.

Why. A record fixed at its date cannot be adjusted after later measurements. The record also lists every expression of the rule's form that was examined for the proportion, with its distance from the measurement. Later measurements of the proportion, of the share of matter and of the small-scale structure of the dark matter test the record as it stands.

A.3 **When does a measurement count as settling the question?**

What the account holds. A result counts as confirmed when it is established at five standard deviations by at least two independent kinds of measurement.

Why. A standard deviation is the unit in which the distance between a prediction and a measurement is stated, the measurement's own uncertainty. The standard is the Passage's rule of decision, and the record applies it to every prediction. A second, independent kind of measurement guards against an error of method that a single kind of measurement can carry without its stated uncertainty showing it.

A.4 **What does the oldest light say?**

What the account holds. The most precise measurement from the oldest light alone gives a proportion of about 5.37, give or take about 0.05, against the prediction of about 5.36. Every measurement from the oldest light alone lies within about one and a third of its own standard deviations of the prediction.

Why. The oldest light measures the two densities from the heights of the peaks in its pattern of warm and cool spots. The heights of those peaks are set by gravity, by sound in the hot early gas, by the scattering of light on free electrons, and by the forming of atoms; they depend on the dark matter only through its weight and through its taking no part in the sound. The most precise combination, from the South Pole Telescope, the Planck satellite and the Atacama Cosmology Telescope, lies within less than one sixth of a standard deviation of the prediction.

A.5 **Is six less two divided by pi not a number chosen to fit?**

What the account holds. No. The rule is not one number picked from a range: it is one member of a small family of expressions that have the form of the Passage's rule for the cosmological constant. Within that form, four choices of which bending abides are possible, and the measurement admits one.

Why. With no bending abiding, the proportion would be exactly six; with the sphere's bending alone abiding, about 5.68; with all of the internal bending abiding, about 5.05. The measurement excludes all three, and admits the account's choice. Counted by three kinds alone, the proportion would lie below three, which the measurement also excludes. The rule is supported by its form, by the exclusion of its neighbors within that form, and by the number it shares with the Passage's rule. That shared number gives the rule a test of its own: the rule for the dark matter and the Passage's rule are two measurements of one number, and the two must agree.

A.6 **What do the surveys of the spacing of galaxies add?**

What the account holds. Combinations that add a survey of the spacing of galaxies, from the Dark Energy Spectroscopic Instrument, give a lower proportion, the most precise of them at about 5.20. On this account, the preference of those surveys for a lower share of matter will shrink as their data grow.

Why. The spacing of galaxies does not measure the dark matter directly; it measures the share of matter in the universe, and a lower share lowers the fitted density of dark matter. The same combinations also favor a share of matter below the Passage's share, 0.311. Without the survey of the spacing of galaxies, the two rules agree. The coming surveys will measure the share of matter far more precisely, and a second, independent kind of measurement of the two densities, at the same precision, will settle the proportion.

A.7 **Is there a second kind of measurement?**

What the account holds. Yes. Routes that do not use the oldest light measure the share of ordinary matter in all the matter, and each such route agrees with the prediction, about 0.156 (slightly less than one in 6.36, because the lightest neutrinos take a small part of the matter).

Why. One route takes the amount of ordinary matter from the making of the lightest elements, and the share of matter from the spacing of galaxies. Another takes the share of ordinary matter in all the matter from the gas held in clusters of galaxies. These routes are less precise than the oldest light: the best of them about five times less, and the cluster gas about thirty times less. At the precision of the oldest light, they would supply the second, independent kind of measurement that the rule of decision requires.

A.8 **How are the rule for the dark matter and the rule for dark energy tested together?**

What the account holds. The two rules share one number, the bending of the internal dimensions, which the Passage sets at one in natural units, so the two must find the same value of it.

Why. The proportion of dark matter measures that shared number at about 0.99, give or take about 0.08, in agreement with the Passage's one. The share of matter in the universe measures the same number, more loosely.

A.9 **Will the energy of empty space be found constant?**

What the account holds. Yes, on this account: the constant that drives the expansion is exactly constant, at every era.

Why. The Passage derives it as the one constant term of the equations of space and time. Some combined surveys report a hint of a slow change, at about three standard deviations. The coming surveys will settle the ques-

tion, and on this account they will find the energy of empty space constant. *The View from Inside*, in its Appendix B, sets out what those surveys will measure.

A.10 **Will a detector ever find the dark matter?**

What the account holds. No detector will ever catch the dark matter by any means other than its weight. It will not be caught by a collision in an underground tank, by light or particles that it gives off, or by being made in a collider.

Why. The dark matter is a vibration of context, and detectors register content. Other accounts of dark matter that acts only by its weight make the same prediction for these searches, so a lasting absence of any detection separates this account from accounts of weakly interacting particles, but not from those. Weighing a single gyration by its weight alone would test the mass of the gyrations directly; it needs sensors far quieter than any yet built.

A.11 **Does the account say anything about ordinary matter?**

What the account holds. The account holds only if nothing in the world responds to the handedness of the internal sphere, that is, to which direction of turning on its surface counts as clockwise. That nothing in the world responds to the handedness of the internal sphere is a prediction about the content of the world.

Why. The weak force of ordinary matter tells left from right in the open space we live in. The swap of opposite points of the internal sphere leaves left and right in that space unchanged, so the weak force does not contradict the prediction.

A.12 **How could we know that the dark matter is perfectly cold?**

What the account holds. Perfectly cold dark matter clumps on every small scale, with no lower limit to the size of its clumps set by its own motion.

Why. Warmer forms of dark matter move fast enough to smooth out the smallest clumps. Present observations, such as the counts of the faintest satellite galaxies and the small clumps seen by the bending of light, find no such limit: any limit must lie below about ten million times the mass of the Sun.

A.13 **Do the motions of galaxies call for a change in the law of gravity?**

What the account holds. No. In the account, the law of gravity stays unchanged, and the dark matter supplies the pull that a changed law would be asked to supply.

Why. The motions of galaxies do follow their visible matter very closely. In 153 disc galaxies measured closely, the pull found from the rotation at each radius is one function of the pull that the visible stars and gas alone would give: it follows the visible matter where that pull is strong, and departs from it more and more as that pull falls to about one ten-billionth of a meter per second per second and below. The account offers no explanation of that closeness beyond what the formation of galaxies under ordinary gravity provides. The changed law of gravity predicts that a galaxy falling freely in the field of a larger one feels an extra effect from that field; under general relativity, which the Passage derives, a galaxy feels the larger field only through its tide.

A.14 **How strongly has matter clumped by today?**

What the account holds. The account gives a definite value for how strongly matter has clumped by today, once the starting strength of the early departures is taken from the oldest light. In the measure astronomers use, called S8, the value is about 0.823, give or take 0.006.

Why. The share of matter, the proportion of dark to ordinary matter and the perfect coldness of the dark matter together fix how the early departures grow. The gyrations are so heavy that their own motion fades as the universe expands. Even a gyration that left the turn at nearly the speed of light has moved less than a meter on its own in the whole history of the

universe, so the gyrations clump exactly as the cold dark matter of the standard picture does. The standard picture, fitted to the same oldest light, gives about 0.832 with twice the uncertainty, because it fits the share of matter that the Passage fixes. The bending of the oldest light by the matter it passes, the complete survey of the shapes of distant galaxies by the Kilo-Degree Survey, and the motions of galaxies all agree with the account's value.

A.15 **Can we measure the shape of the internal dimensions?**

What the account holds. Yes, on the condition that the rule holds. The proportion of dark matter to ordinary matter depends on how the bending of the internal space divides between its two factors, so measuring the proportion measures that division.

Why. The Passage gives the two factors of the internal space a definite ratio of sizes. Measurements of the oldest light alone give a ratio of sizes in agreement with the Passage's, within their uncertainty. A coming observatory, the Simons Observatory together with the Planck data, is forecast to measure that ratio to about eight percent. The test of the shape and the test of the rule are one measurement, not two.

A.16 **Can the count of one for the visible space be tested?**

What the account holds. Yes. The count of one holds if no closed path anywhere in space goes around the universe and is shorter than the width of the horizon.

Why. Searches of the oldest light find every such path through our location longer than ninety-eight and a half percent of the width of the sphere from which that light comes. So the region within the horizon is shown to be a ball out to ninety-six and a half percent of the horizon's radius.

A.17 **What does the Passage predict that bears on this account?**

What the account holds. The Passage predicts that waves of the geometry from the beginning of the epoch lie far below present limits, that the present epoch is spatially flat, and that the dark and the ordinary matter carry one pattern of early departures, the same from place to place.

Why. Each of these concerns the turn, where the dark matter is made, and the measurements of the oldest light reach all three.

Words Used in This Book

Abiding. To abide is to hold fast. In the account, the abiding is the share of the bending of the internal space that holds fast as a term of its own and is deducted from a count: two divided by pi for the four dimensions shaped by three alternatives, and three divided by pi for the whole internal space. The sphere's bending does not abide in a count that already includes the sphere's two kinds.

Content. What a measurement registers: a pattern, a force or a probability. The ordinary matter is content.

Context. Where a measurement registers its content: space, time or possibility. The three things that bend the world bend its contexts.

Cosmological constant. The constant term in the equations of space and time, the same at every place and at every time, often called dark energy. It distorts time, and it drives distant places apart.

Dark matter. On this account, a lasting vibration of the six internal dimensions, made only at the turn between epochs. It distorts possibility, and it acts on everything else only by its weight.

Epoch. One cycle of the universe, from one turn to the next. Our universe since its Big Bang is the present epoch.

Gyration. A conserved excitation of the six held internal dimensions, a lasting vibration of their geometry; the dark matter is made of gyrations. A gyration has a mass of about the Planck mass: about six tenths of a Planck mass with the first correction, and one and two fifths in the simplest calculation.

Horizon. The horizon is the boundary of the space within which anything can ever be compared with us, and that boundary is the edge of space. Where the account counts what a measurement holds, the horizon meant is the particle horizon: the boundary of what has been compared with us so far, as far as light has traveled since the turn.

Internal space. The six small dimensions that the Passage adds to the four of space and time. Four of them have the shape of the possible states of a system with three alternatives, and two have the shape of a sphere, the possible states of a system with two.

Microwave background. The oldest light in the universe, released early in the present epoch. Its pattern of slightly warmer and cooler spots records the amounts of ordinary matter and of dark matter.

Ordinary matter. Everything made of atoms: stars, gas, planets and people. Physicists call it baryonic matter.

Planck scale. The scale of about the Planck length, which bounds how sharply anything can be located (it is not a least length of space), and the scale at which the internal dimensions are held. The sphere is held at a radius of one Planck length and the other factor at about two and a half Planck lengths; the Planck mass is the unit of mass at that scale, about ten billion billion times the mass of a proton. It is the edge of possibility.

Standard deviation. The unit in which the distance between a prediction and a measurement is stated: the measurement's own uncertainty. The account counts a result as confirmed at five standard deviations, by two independent kinds of measurement.

Turn. The transition from one epoch to the next, in which the collapse inside the black holes of one epoch and the beginning of the next are one transition, approached from its two sides. It is the edge of time.

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