CHAPTER 11

COINCIDENCE, PROVIDENCE – OR MULTIVERSE?

> On religion I tend towards deism but consider its proof largely a problem in astrophysics. The existence of a cosmological God who created the universe (as envisaged by deism) is possible, and may eventually be settled, perhaps by forms of material evidence not yet imagined.
>
> E. O. Wilson, *Consilence*

WHAT DOES THE FINE TUNING MEAN?

In our universe, intricate complexity has unfolded from simple laws. But it's not guaranteed that simple laws permit complex consequences; indeed, we've seen that different choices of our six numbers would yield a boring or sterile universe. Similarly, mathematical formulae can have very rich implications, but generally they don't. The Mandelbrot set, for instance, with its infinite depth of intricate structure, is encoded by a short algorithm (see Figure 11.1). But other algorithms, superficially similar, yield very dull patterns.

There are various ways of reacting to the apparent fine tuning of our six numbers. One hard-headed response is that we couldn't exist if these numbers weren't adjusted in the appropriate 'special' way: we manifestly *are* here, so there's nothing to be surprised about. Many scientists take this line, but it certainly leaves *me* unsatisfied. I'm impressed by a

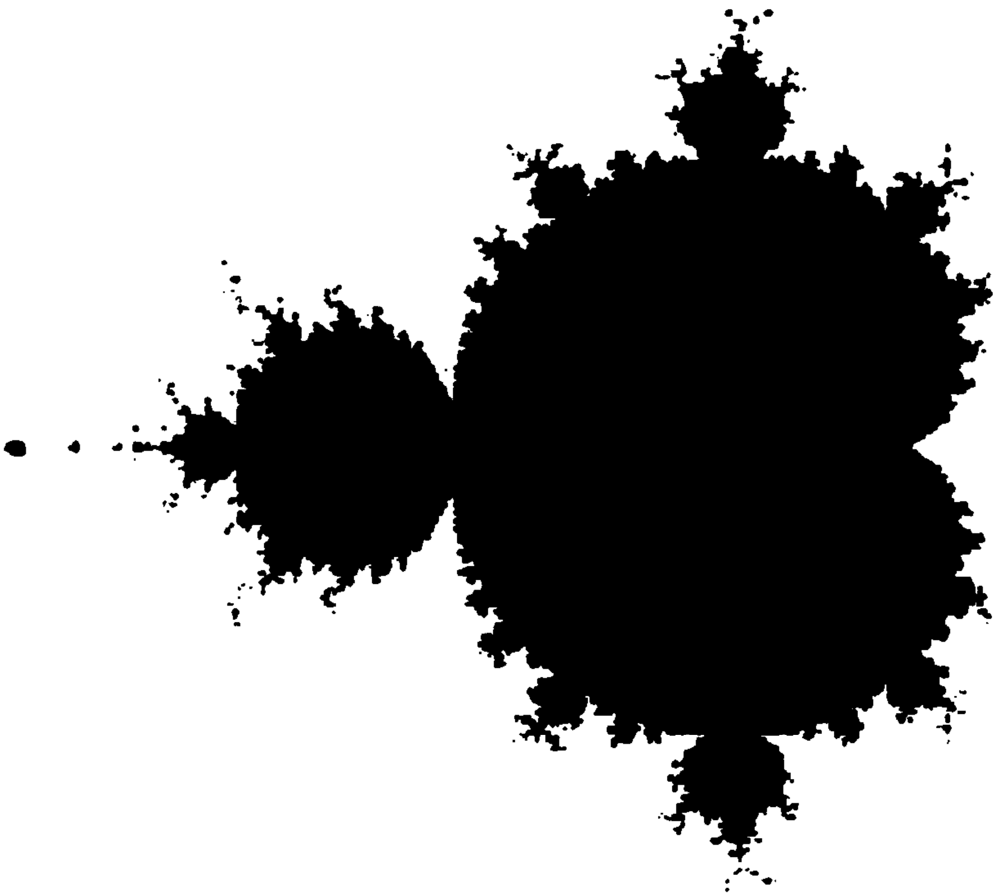

FIGURE 11.1

The Mandelbrot set. This infinitely complex pattern, which contains layer upon layer of intricate structure, is encoded by a short and simple algorithm. But many similar-seeming algorithms describe dull and featureless patterns. Our universe is governed by laws that permit immensely varied consequences.

metaphor given by the Canadian philosopher John Leslie. Suppose you are facing a firing squad. Fifty marksmen take aim, but they all miss. If they hadn't all missed, you wouldn't have survived to ponder the matter. But you wouldn't just leave it at that – you'd still be baffled, and would seek some further reason for your good fortune.

Others adduce the 'tuning' of the numbers as evidence for a beneficent Creator, who formed the universe with the specific intention of producing us (or, less anthropocentrically, of permitting intricate complexities to unfold). This is in the tradition of William Paley and other advocates of the so-called 'argument from design' for God's existence. Variants of it are now espoused by eminent scientist-theologians such as John Polkinghorne; he writes that the universe is 'not just "any old world", but it's special and finely tuned for life because it is the creation of a Creator who wills that it should be so'.[1]

If one doesn't accept the 'providence' argument, there is another perspective, which – though still conjectural – I find compellingly attractive. It is that our Big Bang may not have been the only one. Separate universes may have cooled down differently, ending up governed by different laws and defined by different numbers. This may not seem an 'economical' hypothesis – indeed, nothing might seem more extravagant than invoking multiple universes – but it is a natural deduction from some (albeit speculative) theories, and opens up a new vision of our universe as just one 'atom' selected from an infinite multiverse.

THE MULTIVERSE

Some people may be inclined to dismiss such concepts as 'metaphysics' (a damning put-down from a physicist's viewpoint). But I think the multiverse genuinely lies within the province of science, even though it is plainly still no more than a tentative hypothesis. This is because we can already map out what questions must be addressed in order to put it on a more credible footing; more importantly (since any good scientific theory must be vulnerable to being refuted), we can envisage some developments that might rule out the concept.

The prime stumbling-block is, of course, our perplexity about the extreme physics that applied in the initial instants after the Big Bang. There are strengthening reasons to take 'inflation' seriously as an explanation for our expanding universe: the theory's firmest and most generic prediction, that the universe should be 'flat', is seemingly borne out by the latest data (albeit not in the simplest form: three ingredients – atoms, dark matter, and the vacuum energy λ – contribute to the 'flatness'). The actual details of inflation depend on the physical laws that prevailed in the first 10^{-35}seconds, when conditions were so extreme as to be far beyond the range of direct experiment. But there are two ways we can, realistically, hope to pin down what those conditions were. Firstly, the ultra-early universe may have left conspicuous 'fossils' in our present-day universe. For example, clusters and superclusters of galaxies were 'seeded' by microscopic fluctuations that arose during inflation, and their detailed properties, which astronomers can now study, hold clues to the exotic physics that prevailed when these structures were laid down. Secondly, a unified theory may earn credibility by offering new insight into aspects of the microworld that now seem arbitrary and mysterious – for instance, the various types of subatomic particles (quarks, gluons, and so forth) and how they behave. We would then have confidence in applying the theory to the inflationary era.

Advances along these two routes may disclose to us a convincing description of the physics of the ultra-early universe. Computer simulations of how universes emerge from something of microscopic size would then be just as believable as our current calculations of how helium and deuterium were formed in the first few minutes of the expansion (Chapter 5) and how galaxies and clusters emerged from small fluctuations (Chapter 8).

Linde and others have already simulated some 'virtual multiverses', but at the time of writing this book the input into their calculations is highly arbitrary: many speculative options seem open, and we have no way of deciding among them. These studies of 'eternal inflation' (described in Chapter 9) already show us that some sets of assumptions, consistent with everything else we know, yield many universes that sprout from separate Big Bangs into disjoint regions of space-time. These universes would never be directly observable, even in principle; we couldn't even meaningfully say whether they existed 'before', 'after' or 'alongside' our own. However, if the input theory that predicted multiple universes could be 'battle-tested' by convincingly explaining things we *could* observe, then we should take the other (unobservable) universes seriously, just as we give credence to what our current theories predict about quarks inside atoms, or the regions shrouded inside black holes.

If there are indeed many universes, the next question that arises is: How much variety do they display? The answer again depends on the character of the physical laws at a deeper and more unified level than we yet understand. Perhaps some 'final theory' will give unique formulae for all of our six numbers. If it were to, then the other universes, even if they existed, would in essence be just replicas of ours, and the apparent 'tuning' would be no less a mystery than if our single universe were the whole of reality. We'd still be perplexed that a set of numbers imprinted in the extreme conditions of the Big Bang happened to lie in the narrow range that allowed such interesting consequences ten billion years later.

But there's another possibility. The underlying laws that apply throughout the multiverse may turn out to be more permissive. Each universe may evolve in a distinctive way, being characterized by a different set of numbers from those that are so crucial moulding our own universe. We are used to explaining contingencies here on the Earth (why there is a particular mountain, for instance), and even features in space (the shape of a nebula, the pattern of the galaxies), as 'accidents of history'. We can't explain such things any more deeply, although we don't doubt that they are the outcome of some underlying laws. By extension, the strength of the forces and the masses of elementary particles (as well as Ω, Q and λ) could be secondary outcomes of the final theory (maybe a version of superstring theory) that governs the entire multiverse.

There is an analogy here with a 'phase transition', such as the familiar phenomenon of water turning into ice. When the inflationary era of a particular universe ended, space itself (the 'vacuum') underwent a drastic change. The fundamental forces – gravitational, nuclear, and electromagnetic – all 'froze out' as the temperature dropped, fixing the values of $\mathcal{N}$ and $\mathcal{E}$ in a manner that can be considered 'accidental', just like the pattern of ice crystals when water freezes. The number $\mathcal{Q}$, imprinted by quantum fluctuations when a universe was of microscopic size, may also depend on how these transitions occur.

Some universes may manifest different numbers of dimensions, depending on how many of the initial nine spatial dimensions compactify rather than stretch. Even in three-dimensional spaces, there may be different microphysics, and perhaps different values of λ, depending on the type of six-dimensional space into which the other dimensions curl up. Universes could have different values of Ω (which fixes the density and how long their 'cycle' lasts if they recollapse), and $\mathcal{Q}$ (which measures how smooth a universe is, and so determines what structures emerge in it). In some, gravity could be so overwhelmed by the repulsive effect of the 'vacuum energy' (λ) that no galaxies or stars can form. Or the nuclear forces may be outside the range of ($\mathcal{E}$ close to 0.007) that allows elements like carbon and oxygen to be stable, and to be synthesized in stars: there would then be no periodic table and no chemistry. Some universes could have been short-lived, and so dense throughout their lives that everything stayed close to equilibrium, with the same temperature everywhere.

And some universes might just be too small and simple to permit any internal complexity at all. I have highlighted one basic number, $\mathcal{N}$, that is exceedingly large – one followed by 36 zeros. Its size reflects the weakness of gravity: very large numbers of particles have to gather together before gravity becomes important – as it does, for instance, in stars (gravitationally bound fusion reactors). It's a straightforward consequence of their size that stars have lifetimes that are enormously long, allowing time for photosynthetic and evolutionary processes to unfold on suitable planets in orbit around them. In Chapter 3 we imagined a universe where $\mathcal{N}$ wasn't as huge as 10^{36} but where everything else (including our other five numbers) was unchanged. Stars and planets could still exist, but they would be smaller and would evolve quicker. They would not offer the stretches of time that evolution demands. And gravity would crush anything large enough to evolve into a complex organism.

The recipe for any 'interesting' universe must include at least one very large number: clearly, not much could happen in a universe that was so constricted that it contained few particles. Every complicated object must contain a large number of atoms; to evolve in an elaborate way, it must also persist for a long time – many, many times longer than a single atomic event.

But an abundance of particles, and a long stretch of time, are not in themselves sufficient. Even a universe as large, long-lived and stable as ours could contain just inert particles of dark matter, either because the physics precludes ordinary atoms from ever existing or because they all annihilate with exactly equal numbers of antiatoms.

THE MYSTERY OF λ

These speculative ideas offer a new perspective on λ, the key number that measures the energy content of empty space. The energy that drove inflation is presumed to have been latent in the vacuum. This means that λ in the remote past was larger by 120 powers of ten than it could possibly be today. In this perspective, it seems surprising that λ should decay away to be so close to zero. There are three very different resolutions of this puzzle.

One is that the microstructure of space (maybe involving a foam-like assemblage of tiny interlinked black holes) somehow adjusts itself to make this so. A second idea is that the

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JUST SIX NUMBERS

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