Is the sky made from pi?

Our concept of the Universe is prey to various numerical interpretations.

Just Six Numbers: The Deep Forces that Shape the Universe
by Martin Rees
Weidenfeld & Nicolson: 1999. 173 pp.
£12.99, $22

The Nine Numbers of the Universe
by Michael Rowan-Robinson
Oxford University Press: 1999. 188 pp.
£16.99, $32.50

Frank Wilczek

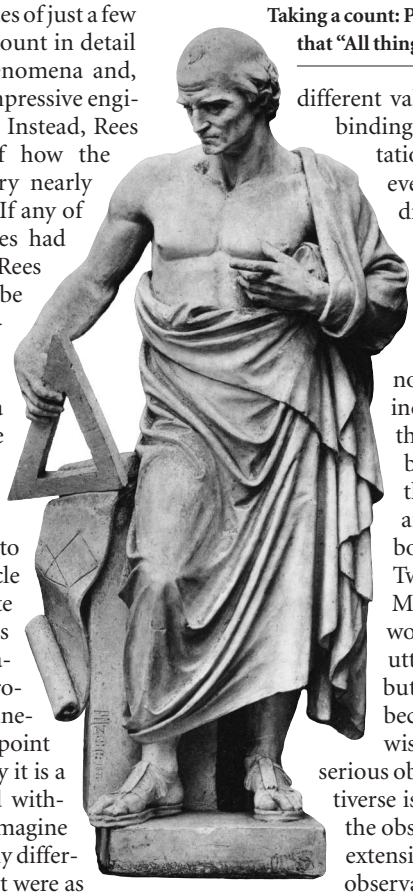
More than two millennia have passed since Pythagoras proclaimed, "All things are Number". Was his proclamation reverie or revelation? In the books reviewed here, two distinguished cosmologists, from profoundly different perspectives, weave popular accounts of their subject around this question.

Developments in physics and astronomy over the past century have brought the Pythagorean vision into sharp focus. The homogeneity of the Universe, and the sameness (or 'universality') of the physical laws throughout, are established by observation. Also, we have a well-tested picture of evolution from a hot, dense, extremely homogeneous phase — the Big Bang. We can codify the physical laws in a remarkably simple, beautiful and mathematically precise set of equations — the so-called Standard Model, plus general relativity.

To fully specify cosmology requires at least the amplitude and slope of the spectrum of primeval fluctuations, the mass fraction in one or several kinds of dark matter, the baryon fraction, the Hubble parameter and the value of the cosmological term. Similarly, to fully specify the Standard Model (including all the heavy quarks and leptons) requires many logically independent parameters.

Thus, our fundamental working models of nature, although containing an elegant and powerful Pythagorean core, begin to look complicated and unsatisfying when fully fleshed out. Moreover, we have learned that there are many questions we should not expect to be able to answer from first principles. Whereas it was reasonable for Johannes Kepler to try to fit the ratios of planetary orbits using ideal mathematical constructions (regular polyhedra), we now understand that these ratios are highly contingent facts, accidents of a unique history.

The title and introduction of Martin Rees's book led me to expect something quite different from what the rest of the book delivers. I had expected to find a celebration of the triumph of Pythagorism — an account of how, given the values of just a few numbers (say 6), you can account in detail for a wealth of physical phenomena and, on the way, do some pretty impressive engineering, by pure calculation. Instead, Rees delivers six case studies of how the Pythagorean programme very nearly goes catastrophically wrong. If any of six specific, chosen quantities had been significantly different, Rees argues, our world would be unrecognizable and intelligent life would most probably be impossible.



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Taking a count: Pythagoras believed that "All things are Number".

Two examples will give a flavour of the argument. The binding energy of protons and neutrons into helium-4 is 0.007 of their rest mass. This number arises, according to modern elementary particle physics, from a rather intricate interplay between the masses of 'up' and 'down' quarks (relative to the basic quantum chromodynamic scale) and the fine-structure constant. From the point of view of fundamental theory it is a remote epiphenomenon, and without absurdity one can easily imagine worlds in which it had a slightly different value. Yet, Rees argues, if it were as small as 0.006, deuterium would be unbound and no elements other than hydrogen would be created; while if it were as large as 0.008, stellar evolution would be so fast and violent that life as we know it could not evolve.

The ratio of the strength of gravitational to electric forces, for protons, is about 10^{-36}. This extraordinary number arises, according to a rather more uncertain extrapolation of modern elementary particle physics, as a result of the slow running of the strong coupling constant. If it were significantly larger, gravity on bound systems such as planets would be much more oppressive, and large multicellular creatures would be crushed by their own weight (also stars would evolve faster). If it were significantly smaller, planets would not form in the first place.

In documenting these examples, Rees is moving towards a deeply subversive position. It is becoming increasingly difficult to believe, he argues, that the complex 'fine tunings' of physical parameters that seem to be necessary for the emergence of intelligent life are unique consequences of a simple fundamental theory. He favours instead the idea that we live not in a Universe but rather in a Multiverse, which contains regions with drastically different properties (for example, different values of the nuclear binding fraction, gravitational strength, or even space–time dimensionality). In this framework, the 'fine tunings' could be explained anthropically. They need not have occurred, indeed in most places they do not occur, but where they don't there's no one around to watch the botch!

Twenty years ago the Multiverse concept would have seemed utterly far-fetched, but now it threatens to become conventional wisdom. The most serious objection to the Multiverse is, of course, simply the observational fact that extensive astronomical observations of distant regions of the cosmos have disclosed the basic uniformity, not diversity, of physical law. But the theory of cosmic inflation has made it plausible that the portion of the world we can currently observe might be just a small portion of the whole, an initially tiny (and hence uniform) patch inflated to gigantic proportions. And high-energy theorists working on supersymmetric unified theories and string/M theory find themselves confronted with a bewildering variety of apparently consistent solutions, with nothing to choose between them. Might each have its homeland?

If these ideas are correct, then the irreducible element of contingency we noted above extends much further than commonly allowed. Several of the seemingly 'fundamental' parameters of physics would, in fact, be features of our environment. They could never be calculated directly from fundamental theory without taking a serious detour through anthropism, because they would be consequences of our position in the Universe amidst the larger Multiverse, not of any universal truth.

Thus, Rees is the anti-Pythagoras. Whether or not they are convinced by his major thesis, readers will find Rees's short,

well-written book an enjoyable and provocative intellectual adventure.

Michael Rowan-Robinson's book represents, by comparison, down-to-earth cosmology. He discusses the key observations — past, present and future — in much greater depth, including frequent and strenuous warnings about their uncertainties, yet he does so concisely. In the penultimate chapter he discusses his own involvement in investigating the starburst-galaxy phenomenon. Although perhaps not quite as grand as the other material, it is in compensation fresh and personal. The two books are in many respects complementary and, by looking at both, a reader could get an excellent, rounded view of the exciting state of contemporary physical cosmology.

Neither of these books, with their heavy focus on the wild-and-woolly frontiers of cosmology, begins to do justice to the truly remarkable triumphs of Pythagorism closer to home. Given five pure numbers — the electron, up- and down-quark masses in units of the quantum chromodynamic scale, plus the fine-structure constant — one can accurately account for all the phenomena of chemistry, and the structure of ordinary matter. Add a couple more — Newton's gravitational and Fermi's weak-coupling constants — and essentially all of astrophysics and most of cosmology enter the charmed circle of understanding. Small parts of this great scientific success story have been told, but it has yet to find its Milton. ■

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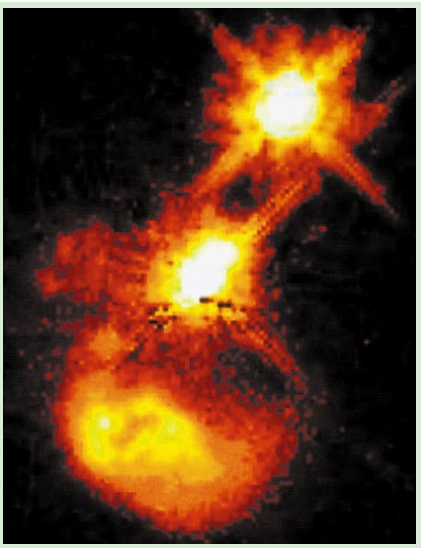


Quasars, nebulae, and more

With the Hubble telescope quasars can be imaged in great detail, such as quasar IRAS 04505–2958, some 3 billion light years away, shown here. The image comes from *Deep Space: New Pictures From the Hubble Space Telescope* (Constable, £16.99), a collection of recent Hubble images, with an explanatory text by Simon Goodwin and John Gribbin.

Arctic antics

Ice Finders: How a Poet, a Professor, and a Politician Discovered the Ice Age
by Edmund Blair Bolles
Counterpoint: 1999. 256 pp. £16.50, $24

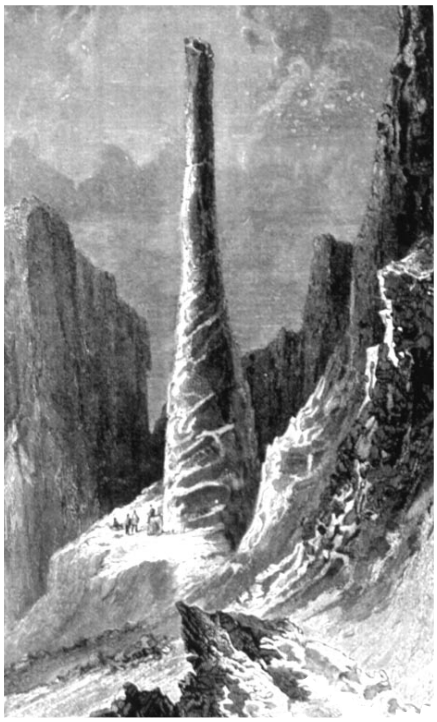
Douglas Palmer

The Ice Finders by Edmund Blair Bolles is about the struggle for scientific acceptance of the evidence for a recent Ice Age. Although a good idea for a popular science book, it is curiously constrained by its alliterative subtitle — the 'poet' is Elisha Kent Kane, the 'professor' Louis Agassiz and the 'politician' is Charles Lyell. Kane was, in fact, an assistant surgeon in the US Navy, who led the 1853–55 US expedition of the *Advance* in search of Sir John Franklin and the existence of an open, ice-free Arctic Ocean. Agassiz, the Swiss expert on fossil fish and glaciation, was indeed a professor at the Academy of Neuchâtel and subsequently Harvard, and the British 'encyclopaedic' geologist Lyell was one of the best-known Earth scientists of the time.

Bolles sets out his methodological 'stall', in a chapter entitled "Ignorant, ambitious men", by declaring that "the most famous law of mechanical intelligence says: Garbage in, garbage out". Consequently, Lyell's book (*The Principles of Geology*, 1830) becomes, "as far as the Ice Age was concerned ... another case of garbage in". To be fair, Bolles is writing popular science, but I find such simplistic clichés irksome. I doubt whether they are really necessary to 'hook' the reader if there is a good story to tell, and basically there is a good story here.

The conceit of the plot lies in the interweaving of the narrative of Kane's expedition with the more complicated stories of the discovery and interpretation of glacial phenomena by Agassiz, Lyell and their contemporaries at least a couple of decades earlier. Kane's story is well told, but has the feel of being shoehorned into the narrative. Presumably Bolles, an American, wanted a 'homegrown' hero as a foil to the predominance of European characters. Eventually, the strands are pulled together when Kane returns and publishes an account of his travels and scientific observations (*Arctic Explorations in the Years 1853, '54, '55*, 1856), with an encomium by Agassiz.

In order to make the Kane story more relevant to the plot, Bolles has to downplay earlier Arctic exploration and public awareness of polar ice fields. He claims that "most people never saw, never heard of the great ice. Presumably Erik the Red and a few other Vikings who made it to Greenland had some idea." However, Clive Holland (*Arctic Exploration and Development c. 500 BC to 1915*, Garland, 1994) estimates that the Viking population of Greenland may have numbered as many as 3,000 around the first millennium. Holland also lists hundreds of expeditions to the Arctic before the 1820s by, among others, Russian, Scandinavian, French and British explorers.



FROM KANE'S *ARCTIC EXPLORATIONS IN SEARCH OF SIR JOHN FRANKLIN* (NELSON, 1902)

Polar prominence: Kane's sketch of a column of greenstone encountered during his explorations.

As for public awareness, "The ice was here, the ice was there,/The ice was all around:/It cracked and growled, and roared and howled, ..." — Samuel Taylor Coleridge's *The Rime of the Ancient Mariner*, published in1798, was all around as well. The poem enjoyed enormous success and subsequent influence. In addition, the *Quarterly Review* of 1817 and 1818 devoted two long articles to Arctic exploration which, along with Coleridge's poem, are thought to have stimulated Mary Shelley's use of the Arctic in her novel *Frankenstein, or, The Modern Prometheus*, published in 1818. Her explorer, Captain Robert Walton, writes that, "We are still surrounded by mountains of ice, still in imminent danger of being crushed in their conflict. The cold is excessive ... Frankenstein has daily declined in health ..." Surely, there is an interesting story here about the growing public fascination with the polar regions from the turn of the century.

The real meat of the Bolles story is the discovery and argument over the nature of glacial phenomena such as erratics, parallel roads and scratched rock surfaces. This part