by which to choose among this vast range of solutions, it does not seem particularly useful to claim that any one string theory is unique.

Stephen Hawking and Thomas Hertog[3], writing in *Physical Review D,* now propose arms to be taken against this sea of troubles. The arms they propose are admittedly not new, having been developed[4] in the 1980s by Hawking, James Hartle and others. Then, too, the motivation was uniqueness of solutions: specifically, if a quantum-cosmological model explains properties of our Universe (of which, by definition, we see only one), then it should also explain why this, and only this, solution emerges. Such a model can be compared with observations, making the whole framework testable and thus predictive.

Hartle and Hawking called their condition for establishing uniqueness[4] the no-boundary proposal, because it removed the boundaries of space-time. According to this view, the Universe is a closed surface — rather like a surface of an inflating balloon — and has no beginning in time. Such a closure of space-time is not meaningful in classical general relativity, and thus requires the introduction of aspects of quantum theory. This in turn serves to establish uniqueness: although there are several possible closures, quantum theory can, unlike classical theory, deal with all of them at once as a probabilistic superposition. Alternatives to the Hartle–Hawking proposals include Alexander Vilenkin's proposal that the Universe initially tunnels out of a quantum state where space and time are not defined[5], and more recent models based on new formulations of quantum gravity.

In their recent paper[3], Hawking and Hertog refresh the no-boundary proposal, adding new insight and giving it a new name: top-down cosmology. Looking at a space-time diagram where time runs in the upward direction, the conventional approach to cosmology is 'bottom-up' (Fig. 1a): one starts with initial conditions in the past and calculates forward to aim at properties seen now. This process usually requires very specific, fine-tuned initial values. The top-down approach (Fig. 1b) avoids this problem by taking the properties of the Universe as it appears now and calculating its history backwards. This process is applied to a quantum superposition of different Universe states, with 'final', rather than initial, conditions being set to select one history in the superposition relevant for our observations. In this way, the non-intuitive quantum superposition is reduced to a classical Universe as we observe it.

Traditional bottom-up cosmologies also suffer from the problem that they break down at points where infinite energies arise in solutions of the equations of general relativity. These points are known as singularities, and our Universe may have experienced one at the Big Bang. Starting from a simple initial state that explains the emergence of the Universe, the chances are that one will run into a singularity before even getting close to the present. On its own, the top-down approach is not free from this problem, as the probability of hitting a singularity when calculating backwards is just as great as when calculating forwards. But when combined with the no-boundary proposal, top-down is safer: this combination has the effect of closing off singularities from classical space-time before the history being traced can approach them. Again, this act of closing off introduces aspects of quantum theory, and leads directly to a quantum description of gravity.

The arguments that Hawking and Hertog present are not complete, as they distinguish only between 'classical bottom-up' and 'quantum top-down'. That mixes up the singularity problem, which is a matter of classical against quantum theory, with the issue of predictivity. This second point amounts to what preconditions, whether initial or final, we may set when evaluating a theory and is the dividing line between bottom-up and top-down theories. Elsewhere in physics, it is clear which approach is better: one predicts final observations from the initial set-up of an experiment. But this option is clearly not available in cosmology, as we have no influence over the initial conditions of the Universe. Hawking and Hertog's suggestion is indeed a radical shift of approach: it is, as befits the description of the evolution of the Universe, much more akin to the holistic methods of 'universal history' (advocated in an early form by Friedrich Schiller in his inaugural lecture at Jena in Germany in 1789)[6] than anything familiar from the physical sciences.

A further imprecision is that the authors sometimes use 'top-down' and 'no-boundary' interchangeably, although these are different concepts. That undermines some claims and disregards alternatives: there are, for instance, more general solutions of the singularity problem that do not require a top-down approach; and theories of decoherence[7–10] provide detailed descriptions of the quantum–classical transition as a physical process in which a superposition evolves into a semiclassical history.

Hawking and Hertog present examples[3] for final conditions that can be chosen as the starting point for the backwards computation of the Universe's history. Currently, that choice is wide open, and no clear line is drawn between anthropic conditions — conditions that must be so, because otherwise we humans could not be there to observe them — and conditions that arose accidentally during the development of the Universe, but are nonetheless regarded as important for the purposes of the computation. The fewer final conditions there are, the more predictive a theory will be. What is considered an accident or not is often just theoretical prejudice. Not distinguishing between 'accidental' and other conditions in the determining final set allows one to escape a firm decision, but could undermine the top-down approach by relinquishing deeper explanations. Indeed,

50 & 100 YEARS AGO

50 YEARS AGO

'The neutrino' — While careful reasoning from experimental evidence gathered about all terms in the beta-decay process... may support the inference that a neutrino exists, its reality can only be demonstrated conclusively by a direct observation of the neutrino itself...Such an experiment is made possible by the availability of high beta-decay rates of fission fragments in multi-megawatt reactors and advances in detection techniques. An estimate of the neutrino flux available from large reactors shows that a few protons should undergo reaction in 50 litres of water placed near the reactor... The complete detector consisted of a 'club sandwich' arrangement employing two target tanks between three detector tanks... located deep underground near one of the Savannah River Plant production reactors of the United States Energy Commission...After running for 1,371 hr., including both reactor-up and reactor-down time...a signal dependent upon reactor-power, 2.88 ± 0.22 counts/hr. in agreement with the predicted cross-section (6×10^{-44} cm.^{2}) was measured...
Frederick Reines and Clyde L. Cowan, jun.

From *Nature* 1 September 1956

100 YEARS AGO

'Thermodynamic reasoning' — In the address delivered by Principal Griffiths at York... I read: "Prof. Armstrong remarks that it is unfair to 'cloak the inquiry by restricting it to thermodynamic reasoning'...He adds that such a course may satisfy the physicist but 'is repulsive to the chemist'."

This statement shows a strange misapprehension of my position...At present, progress is not a little hampered by the fact that chemists and physicists cannot wander through the museums of nature in complete sympathy with one another...a confusion of language has arisen which keeps us apart: we must both strive to speak a simpler language.

From *Nature* 30 August 1906