same everywhere; in addition, an exponentially expanding Universe tends asymptotically towards a 'flat' cosmology, whose density approaches the critical density separating universes that expand forever from those that recollapse, whereas a conventional universe filled with radiation and particles diverges away from flatness. Inflation, therefore, was able to explain in principle how the Universe could have lived so long, yet still be near the critical density and be reasonably uniform.

The difficulty is that the Universe, after going through the exponential inflationary phase, must return to something that looks like a conventional universe of matter and radiation. In Guth's original proposal — old inflation — two Higgs vacuum states were separated by a finite energy barrier, and inflation occurred because the Universe got stuck in the higher of the two states. Guth then assumed that quantum tunnelling through the barrier to the low (zero energy density vacuum) state would bring the Universe back to normality. This certainly can happen, but what it creates is an expanding bubble of 'true' vacuum separated from a sea of 'false' vacuum by a material wall (as in a soap bubble) in which energy and particles reside. Old inflation failed because, in the return from the inflationary to the conventional phase, the appearance of these bubbles created a wildly inhomogeneous universe and erased all the advantages of inflation.

Then came 'new inflation'[3,4] in which the barrier between false and true vacua was made to be tiny, and the vacuum state rolled unimpeded from false to true vacuum during the period of exponential expansion. But it could roll neither too fast, or inflation would be curtailed before it could do its job, nor too slowly, or the failings of old inflation would reappear. Moreover, as the vacuum state rolled across an almost flat potential energy surface, small place-to-place variations in its position tended to grow, which led to cosmological density variations: these were desirable, in that they might lead to galaxy formation, but their scale and magnitude were sensitively dependent on the rate of rolling.

New inflation worked, but only if the form of the potential energy surface was just so: a small industry briefly flourished as people tried to construct suitable potentials from supersymmetric or technicolour or Kaluza–Klein theories. The besetting problem was that the construction of suitable potentials required so much fine-tuning and adjustment of parameters that it was hard to believe that nature would be so kind; the whole point of inflation was to avoid fine-tuning cosmological initial conditions, but new inflation put the fine-tuning in the particle physics instead.

What Steinhardt suggests is almost a return to old inflation. In his model of 'extended inflation', the barrier between true and false vacuum is finite again, and quantum tunnelling is what ends inflation. But the new ingredient is a variation of the strength of gravity, coupled somehow to the cosmological expansion. This adds a new term to the conventional Friedman equation relating expansion rate to energy density, and in effect stretches out inflation from an exponential expansion into a mere power law. The extended period of power-law expansion accomplishes the same goals as exponential inflation, although it takes longer. But at this slower pace, bubbles of true vacuum, when they emerge, also expand more slowly, and are able to mix and homogenize the material content of the Universe quickly enough to establish a 'normal' Universe in time for nucleosynthesis, for example, to take place.

Steinhardt's proposal may have another bonus. Old and new inflation both predict that the density of the Universe today can differ from the critical value by only an exponentially small amount. Astronomers, unfortunately, persist in believing that their observations indicate a cosmological density of probably about half the critical value. Some enthusiasts for inflation insist that the cosmological observations are wrong, or at least incomplete; others resort to more fine-tuning to coax a subcritical density from an inflationary theory. But extended inflation offers another way out. Again by virtue of its power law rather than exponential expansion, critical density is approached more slowly than in old or new inflation, which means that a small, but not ridiculously small, range of initial conditions can lead to a Universe with density something less than critical.

The bugbears of modern cosmology are fine-tuning and tooth fairies — Michael Turner's name for theoretical ideas which turn up in the nick of time to save a cosmological model from demise. Steinhardt's extended inflation throws out a lot of fine-tuning, but brings in one new tooth fairy in the guise of a variation of gravity. But the gravity variation does not, apparently, have to follow any particular functional form (so we are not dealing with a finely-tuned tooth fairy), and gravity variation is a tooth fairy of some maturity, having first been seen by Eddington and Dirac. According to these semi-quantitative criteria, therefore, extended inflation looks more credible than most of its rivals. □

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1. Steinhardt, P.J. *Nature* **345**, 47–49 (1990).
2. Guth, A.H. *Phys. Rev.* **D23**, 347–356 (1981).
3. Linde, A.D. *Phys. Lett.* **B108**, 389–393 (1982).
4. Albrecht, A. & Steinhardt, P.J. *Phys. Rev. Lett.* **48**, 1220–1223 (1982).

DAEDALUS

Imperial raiment

MODERN thin-film technology is dominated by vapour-deposition methods. But Daedalus has other ideas. He recalls the old trick of dissolving two chemical precursors of nylon in two immiscible solvents. When the solvents are mixed, they react at their interface to form a nylon film, which can be pulled continuously out of the mixture. DREADCO's chemists are using solutions so dilute, and pulling them from the mixture so fast, that the resulting polymer film is exceedingly thin — much less than a wavelength of light.

The most obvious commercial product is a multi-film laminate. By passing the initial film through a sequence of further dual solvent baths, each adding a layer of a different polymer, a strong and useful multilayered film can be built up. Like float glass, the film retains the optical perfection of the liquid surfaces that formed it. With proper choice of the thickness and refractive index of each layer, an interference filter results: strong, flexible, cheap, as large as you like, and with any desired optical properties.

Already DREADCO's tailors are forming this optical fabric into various 'Emperor's New Clothes'. Some, designed for minimum optical reflection, are practically invisible, but reflect and retain the body's infrared for warmth and comfort. Others combine mirror-like reflectivity in the visible region with total infrared transparency, for maximum heat rejection and cooling in tropical climates. Yet others show the wonderful richness and depth of pure colour that only a multilayer filter can give, or the iridescent rainbow patterns shown by thin soap films.

More appealing still, if the solutions are contacted not as layers but in emulsion form, and the solvent inside the resulting coated droplets is allowed to diffuse out and evaporate, the remaining microballoons form a decorative optical dust with the elusive interference structure of the opal.

With sufficiently dilute solutions, the final film approaches a monolayer, only one molecule thick. Like ultrafine polymer monofilament, it is remarkably strong; yet it is totally invisible. Bulk invisible film is very hard to handle, so the DREADCO workers are concentrating on the emulsion-polymerization form of the process. A powder of hollow monolayer microballoons can be handled and poured like a sort of invisible heavy gas. As the ultimate expanded polymer, it is a wonderful thermal insulator, and the only one transparent enough to be placed between the panes of double-glazed windows. Daedalus hopes to carbonize it into the long-sought spherical hollow graphite macromolecules, of which only the smallest possible example, the C_{60} prototype, has so far been persuasively demonstrated.

David Jones