the likelihood scales inversely with the total number of typical data sets that could have been generated within the theory. The tradeoff between the quality of fit and the statistical complexity is known as Bayesian model selection, and it is used routinely in modern statistics. Against statistically complex theories it provides an *automatic* Occam's razor that depends only weakly on specifics of the priors.

At an extreme, any data set is equally compatible with an unfalsifiable theory and hence can come from it with the same probability. Thus the likelihood is the inverse of the total possible number of experimentally distinct data sets. In contrast, a falsifiable theory is incompatible with some data and hence has a higher probability of generating other, compatible data. The difference between the theories grows with the number of conducted experiments. Thus within Bayesian model selection, any falsifiable theory that fits data well wins eventually, unless the unfalsifiable theory had astronomically higher *a priori* odds. For example, as pointed out by biologist J. B. S. Haldane, evolution cannot generate "fossil rabbits in the Precambrian." Thus Bayesian model selection leads to an immediate empirical, quantitative choice of evolutionary theory over creationism as the best explanation of the fossil record, without the need to reject creationism *a priori* as unscientific.

In other words, there is no need to require falsifiability of scientific theories: The requirement emerges automatically from statistical principles, on which empirical science is built. Its statistical version is more nuanced, as has been recognized by philosophers.[5] The practical applications are hard and require computing probabilities of arbitrary experimental outcomes. In fact, it was an error in such a computation that rekindled the current debate. In addition, there is an uncomfortable possibility that statistics can reject a true theory that just happens to be unfalsifiable. Yet, crucially, statistical model selection is quantitative and evidence driven; it potentially moves the inflationary multiverse debate and similar discussions from the realm of philosophy to that of empirical, physical science. Whereas inflation predicts many different worlds, it is incompatible with others—the theory is not completely unfalsifiable. One can hope to end the long-running arguments about its scientific merits by calculating the relevant likelihood terms.

References

1. P. Steinhardt, *Nature* **510**, 9 (2014).
2. G. Ellis, J. Silk, *Nature* **516**, 321 (2014).
3. S. Carroll, "2014: What scientific idea is ready for retirement?" https://edge.org/response-detail/25322 (2014).
4. D. J. C. MacKay, *Information Theory, Inference, and Learning Algorithms*, Cambridge U. Press (2003).
5. E. Sober, *Ockham's Razors: A User's Manual*, Cambridge U. Press (2015).

Ilya Nemenman
(ilya.nemenman@emory.edu)
Emory University
Atlanta, Georgia

In praise of CETUP*

Recently I thumbed through the April 2015 issue of PHYSICS TODAY and came across the story (page 22) about the South Dakota underground laboratory. I had a chance to stay there for a few weeks last summer and came away with an excellent impression of the lab's potential. That is something that was described quite well in the story.

What I did not see is any mention of the highly successful operation of the Center for Theoretical Underground Physics and Related Areas (CETUP*), which was established only a few years ago and has attracted excellent groups of scientists for summer programs. Especially worthy of mention are the two organizers, Barbara Szczerbinska at Dakota State University and Baha Balantekin with the University of Wisconsin–Madison. Szczerbinska in particular has taken a lot of initiative and done a great deal of work to get CETUP* off the ground. She deserves to be mentioned in an article about the underground lab and its impact on the state as a whole.

Ulrich Mosel
(ulrich.mosel@theo.physik.uni-giessen.de)
University of Giessen
Giessen, Germany

A note on the neutron–proton mass difference

The Search and Discovery story "The neutron and proton weigh in, theoretically," by Sung Chang (PHYSICS TODAY, June 2015, page 17), reports on very important research determining the neutron and proton masses and mass difference. However, the interpretation in the penultimate paragraph, based on hypothetically varying the neutron–proton mass difference—or the electromagnetic coupling strength or other fundamental parameters—is too narrow.

There is strong phenomenological and theoretical motivation for an underlying theory in which the couplings are unified at short distances—a grand unified theory. If they are, then, for example, after Big Bang nucleosynthesis the number of neutrons, and most other relevant quantities, are affected by all the couplings and would change too.[1] Without a calculation of all the combined effects, one cannot draw any reliable conclusions.

Reference

1. G. L. Kane, M. J. Perry, A. N. Zytkow, *New Astron.* **7**, 45 (2002).

Gordon Kane
(gkane@umich.edu)
University of Michigan
Ann Arbor

Material to capture stardust

The cover of the October 2014 issue of PHYSICS TODAY recently caught my eye. I fondly remember participating in the early discussions and conferences to find a physical medium to capture the high-velocity particles that would be encountered during NASA's *Stardust* mission. It was clear from the beginning that a low-density material, some type of foam, was necessary. In 1987 Peter Tsou of NASA's Jet Propulsion Laboratory visited me at Los Alamos National Laboratory to see some of the foams that we were producing for our physics experiments. Most were opaque and polymeric. Included, however, were some silica-based aerogel foams. It was readily apparent that although the aerogel foams did not have the mechanical tenacity and capture capability of the polymeric foams, they had two unmatched properties: The first was very low carbon and hydrogen content as a result of the preparative process. The second was transparency, the property that would lead to aerogel's ultimate selection. The trajectory of the captured particle could easily be determined and the particle could be found at the end of the visible capture track.

It was gratifying to be recognized for my role in the development of the stardust capture media when Tsou wrote about the history of the search and testing of various foam media and the ultimate selection of aerogel to perform the task.[1]

Reference

1. P. Tsou, *J. Non-Cryst. Solids* **186**, 415 (1995).

Joel M. Williams
(science@swcp.com)
Los Alamos, New Mexico ■