the significance of the new findings. Michael Huffman, a primatologist at Kyoto's primate institute, agrees that many social behaviors are likely to be influenced by environmental factors. But others—such as mating preferences—are likely to be consistent throughout a species, regardless of habitat. "If you look long enough, Japanese macaques are still Japanese macaques," he says. And Maria van Noordwijk, a primatologist at Duke University, questions drawing conclusions from small data samples. Hill's study, she notes, covers only one troop.

The bottom line for all these researchers is the need for additional studies. And that takes long-term funding, which is always in short supply. The need to generate results in 2 or 3 years, says San Diego's Moore, forces researchers to return to the same small bands. "People have [difficulty] getting secure funding for studies of wild, undisturbed, initially unhabituated animals, where the most interesting results can easily take 5 to 10 years to start coming in," he says. If that situation doesn't change, he predicts, questions about which traits are inherited and which are flexible could remain unanswered.

–Dennis Normile

COSMOLOGY

Inflation Confronts an Open Universe

It is not often that debates over the finer points of cosmology are played out in the pages of daily newspapers, but last week several British papers gave their readers a glimpse of a passionate dispute between some of the mightiest theorists in the known universe. On one side are Cambridge University cosmologists Stephen Hawking and Neil Turok, and on the other is Stanford University's Andrei Linde. Their disagreement—spelled out in reports awaiting publication in physics journals and currently circulating on the Internet—revolves around how to reconcile events in the earliest moments of the big bang with the other end of time: the eventual fate of the universe.

Many cosmologists had long assumed that the universe contains just enough matter that gravity would eventually halt its expansion to give what is known as a "flat" universe. But recent astronomical evidence suggests that there is not enough matter and that the universe will expand forever, yielding a so-called "open" universe. Hawking and Turok have come up with a mathematical explanation for how a subatomic-sized universe can spring into existence, then transmute into an open-ended, ever-expanding one. But Linde is not convinced. A few days after Hawking and Turok released their paper as a preprint, Linde produced a long paper disputing their conclusions. This was swiftly followed by a rebuttal from the Cambridge researchers.

Both sides invoke inflation theory, which proposes a period of stupendous expansion of the universe, starting when the universe was about 10^{-34} seconds old and lasting perhaps 10^{-32} seconds. Because inflation deftly tackles several prickly problems in cosmology, such as the remarkably even appearance of the universe in every direction, it has become received dogma among most cosmologists. Inflationary models traditionally favor a flat universe. But recent results, ranging from measurements of the recession of distant supernovae to the small changes seen in galactic clusters over recent cosmic history (*Science*, 31 October 1997, p. 799), seem to point to an open universe. As a result, some cosmologists, including Turok and Hawking, have been exploring ways of producing an open, inflating universe.

"What we've found is a new set of solutions that describe the beginning of an open universe," says Turok. The work—accepted for publication in *Physics Letters B* in just 3 days—combines a quantum equation for the universe proposed by Hawking and collaborator Jim Hartle in 1983 with a method of spawning an open universe proposed in 1995 in an influential paper by Turok, Martin Bucher of Princeton University, and Alfred Goldhaber at the State University of New York, Stony Brook.

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CERN

Open debate. Inflation protagonists Stephen Hawking *(top left)*, Neil Turok *(top right)*, and Andrei Linde.

But their solution has a glitch: The approach produces many possible universes, most of which are devoid of matter. To avoid this outcome, Turok and Hawking resort to a controversial fix known as the anthropic principle: If a universe is empty, there will be no one to observe it, so it is not worth considering. Thus, Hawking and Turok discard observerless universes and home in on those with the most matter. But they still end up with a universe that is very sparsely filled: Its mass density is a mere 100th of the critical value for a flat universe.

Linde is not impressed. "This prediction tells us that we must practically live in an empty universe, which disagrees with observations," he says. But Turok counters that the new result "applies only to the simplest versions of inflation." He believes that a more complete theory will predict a mass density closer to 30% of the critical value—a figure currently favored by astronomers. Nonetheless, Linde describes their results as "disastrous."

Linde disputes the pair's use of the Hartle-Hawking "wave function" equation for the universe. "I believe this wave function does not describe the creation of the universe," he says. Instead, Linde offers his own, alternative wave function, based on a quantum tunneling approach. In a paper submitted to *Physical Review*, Linde outlines how, when this equation is combined with the Hawking-Turok model, it predicts a flat universe. He also claims that his own recipe is capable of creating a whole range of open universes from inflation, yet it gives nonsense results if fed the Hartle-Hawking wave function.

Turok contends that Linde's reply is "mathematically inconsistent," adding, "I think what his paper has done is basically thrown a large amount of confusion into the subject." Last week, Turok and Hawking released a rebuttal of Linde's criticism. However, Alan Guth of the Massachusetts Institute of Technology, who invented inflation theory back in 1981, thinks that Hawking and Turok may be fighting the wrong battle, attempting to recast inflation theory in a way that makes it work for an open universe. "I still strongly suspect that the universe will turn out to be flat," says Guth, "because the models of inflation that give open universes seem to me to be somewhat more contrived."

Turok believes forthcoming experimental data will help resolve matters. "The cleanest way to test these theories is to look at the microwave background radiation left over from the big bang," says Turok. "If the universe is open, and if the scenario we are discussing is correct, there will be a distinct pattern of fluctuations on the microwave sky." NASA's Microwave Anisotropy Probe, due to fly in 2 years' time, is designed to look for exactly these kinds of patterns. So too is the European Space Agency's Planck mission, due to fly in 2006. So keep watching those morning papers.

–Andrew Watson

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