The famous Einstein f cosmologists

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THERE are few scientists of whom it can be said that their mistakes are more interesting than their colleagues' successes, but Albert Einstein was one. Few 'blunders' have had a longer and more eventful life than the cosmological constant, sometimes described as the most famous fudge factor in the history of science, that Einstein added to his theory of general relativity in 1917.

Its role was to provide a repulsive force in order to keep the universe from theoretically collapsing under its own weight.

Einstein abandoned the cosmological constant when the universe turned out to be expanding, but in succeeding years, the cosmological constant, like Rasputin, has stubbornly refused to die, dragging itself to the fore, whispering of deep enigmas and mysterious new forces in nature, whenever cosmologists have run into trouble reconciling their observations of the universe with their theories.

Recently, the cosmological constant got propelled back into the news as an explanation for the widely reported discovery, based on observations of distant exploding stars, that some kind of 'funny energy' is apparently accelerating the expansion of the universe. "If the cosmological constant was good enough for Einstein," cosmologist Michael Turner of the University of Chicago remarked at a recent meeting, "it should be good enough for us."

Einstein has been dead for 43 years. How did he and his 80-year-old fudge factor come to be at the centre of a revolution in modern cosmology? The story begins in Vienna with a mystical concept that Einstein called Mach's principle. Vienna was the intellectual redoubt of Ernst Mach (1838-1916), a physicist and philosopher who bestrode European science like a Colossus.

The scale by which supersonic speeds are measured is named for him. His biggest legacy was philosophical; he maintained that all knowledge came from the senses, and campaigned relentlessly against the introduction of what he considered metaphysical concepts in science, atoms for example.

Another was the notion of absolute space, which formed the framework of Newton's universe. Mach argued that we do not see 'space', only the players in it. All side force, was similarly relative and derived somehow from an interaction with everything else in the universe.

"What would become of the law of inertia if the whole of the heavens began to move and stars swarmed in confusion?" he wrote in 1911. "Only in the case of a shattering of the universe do we learn that all bodies, each with its share, are of importance in the law of inertia."

Mach never ventnred a guess as so how teis mysterious interaction would work, but Einstein, who admired Mach's incorrigible skepticism, wasaenamoured of whwt he sometimes scalledeMach's principlp and sometimes salled tee relatavity ofof nertrti He h hp to o .orporore the e coept t ehis n nntheoror f gg ral r rolivitite-whichchahcompmp ed inine15. T Ttatheoeo9desestres h h watteteind enen r disisat or r grve' ' r geomomuy ooe ace e r timemes oducucd the e pnomenengcalleleeravitit . InInge lanan ue ofofhneralalarativive, Macace prininyle s0p-p requiui thatatt spapadtime e huaturur-houldldrbdetetesned elely y iothererotter r energrga thehe iversrsi,nd n nnany itialal cdititin or o ooide i isfenceces- whahal ysicic-s calalp bounuty cononions.s.r Amomototherer tngs,s, nsteieihook t ti to m mt thatatsishououunbe e tmssibib to sosop his s qtiononeor ththuase o of solilicy ooact ——raatomome a ststnrlonener the e nersesen sincncihere e -uld be nothing to compare it to or interact with. So, Einstein was surprised a few months after announcing his new theory, when Karl Schwarzschild, a German astrophysicist serving at the front in World War I, sent him just such a solution, which described the gravitational field around a solitary star.

"I would not have believed that

boundaries that would prevent a star from escaping its neighbours and drifting away into infinite un-Machian loneliness. He worked out his ideas in a correspondence with a Dutch astronomer, Willem de Sitter, which were recently published by the Princeton University Press in Volume 8 of *The Collected Papers of Albert Einstein*.

Like most of his colleagues at the time, Einstein considered the universe to consist of a cloud of stars, namely the Milky Way, surrounded by vast space. One of his ideas envisioned 'distant masses' ringing the outskirts of the Milky Way like a fence. These masses would somehow curl up space and close it off.

His sparring partner de Sitter scoffed at that, arguing these 'supernatural' masses would not be part of the visible universe. As such, they were no more palatable than Newton's old idea of absolute space, which was equally invisible and arbitrary.

In desperation and laid up with gall bladder trouble in February of 1917, Einstein hit on the idea of a universe without boundaries, in which space had been bent around to meet itself, like the surface of a sphere, by the matter within. "I have committed another suggestion with respect to gravitation which exposes me to the danger of being confined to the nut house," he confided to a friend.

This got rid of the need for boundaries — the surface of a sphere has no boundary. Such a bubble universe would be defined solely by its matter and energy content, as Machian principles dictated. But there was a new problem; this universe was unstable, the bubble had to be either expanding or contracting.

The Milky Way appeared to be neither expanding nor contracting; its stars did not seem to be going anywhere in particular. Here was

Einstein said the introduction of the cosmological constant had been the biggest blunder of his life. The remark became part of the Einstein legend. In the years after his death, quantum mechanics transformed the cosmological constant and showed how prescient Einstein had been in inventing it!

sented some kind of long-range repulsive force, presumably that kept the cosmos from collapsing under its own weight.

Admittedly, Einstein acknowledged in his paper, the cosmological constant was "not justified by our actual knowledge of gravitation", but it did not contradict relativity, either. The happy result was a static universe of the type nearly everybody believed they lived in and in which geometry was strictly determined by matter.

"This is the core of the requirement of the relativity of inertia," Einstein explained to de Sitter. "To me, as long as this requirement had not been fulfilled, the goal of general relativity was not yet completely achieved. This only came about with the lambda term."

The joke, of course, is that Einstein did not need a static universe to have a Machian one. Michel Janssen, a Boston University physicist and Einstein scholar, pointed out, "Einstein needed the constant not because of his philosophical predilections, but because of his prejudice that the universe is static."

Moreover, in seeking to save the universe for Mach, Einstein had destroyed Mach's principle. "The cosmological term is radically anti-Machian, in the sense that it ascribes intrinsic properties (energy and pressure-density) to pure space, in the absence of matter," said Frank Wilczek, a theorist at the Institute for Advanced Study in Princeton.

In any event, Einstein's new universe soon fell apart. In another 10 years the astronomer Edwin Hubble in California was showing that mysterious spiral nebulae were galaxies far far away and getting farther — in short that the universe might be expanding.

De Sitter further confounded Einstein by coming up with his own solution to Einstein's equations that described a universe that had no matter in it at all. "It would be unsatisfactory, in my opinion," Einstein grumbled, "if a world without matter were possible." De Sitter's empty universe was also supposed to be static, but that too proved to be an illusion. Calculations showed that when test particles were inserted into it, they flew away from each other. That was the last straw for Einstein. "If there is no quasi-static world," he said in 1922, "then away with the cosmological term."

In 1931, after a trip to the Mount Wilson observatory in Pasadena, California, to meet Hubble, Einstein turned his back on the cosmological constant for good, calling it "theoretically unsatisfactory any-

Mach argued that we do not see 'space', only the players in it. All our knowledge of motion, he pointed out, was only relative to the 'fixed stars'.

In his books and papers, he wondered if inertia, the tendency of an object to remain at rest or in motion until acted upon by an out-

star.

"I would not have believed that the strict treatment of the point mass problem was so simple," Einstein said.

Perhaps spurred in part by Schwarzschild's results, Einstein turned his energies in the fall of 1916 to inven[illegible] universe with

its stars did not seem to be going anywhere in particular. Here was where the cosmological constant came in. Einstein made a little mathematical fix to his equations, adding 'a cosmological term' that stabilized them and the universe. Physically, this new term, denoted by the Greek letter lambda, repre-

mological constant for good, calling it "theoretically unsatisfactory anyway". He never mentioned it again.

In the meantime, the equations for an expanding universe had been independently discovered by Aleksandr Friedmann, a young Russian theorist, and by the Abbe Georges Lemaitre, a Belgian cleric

fudge haunts

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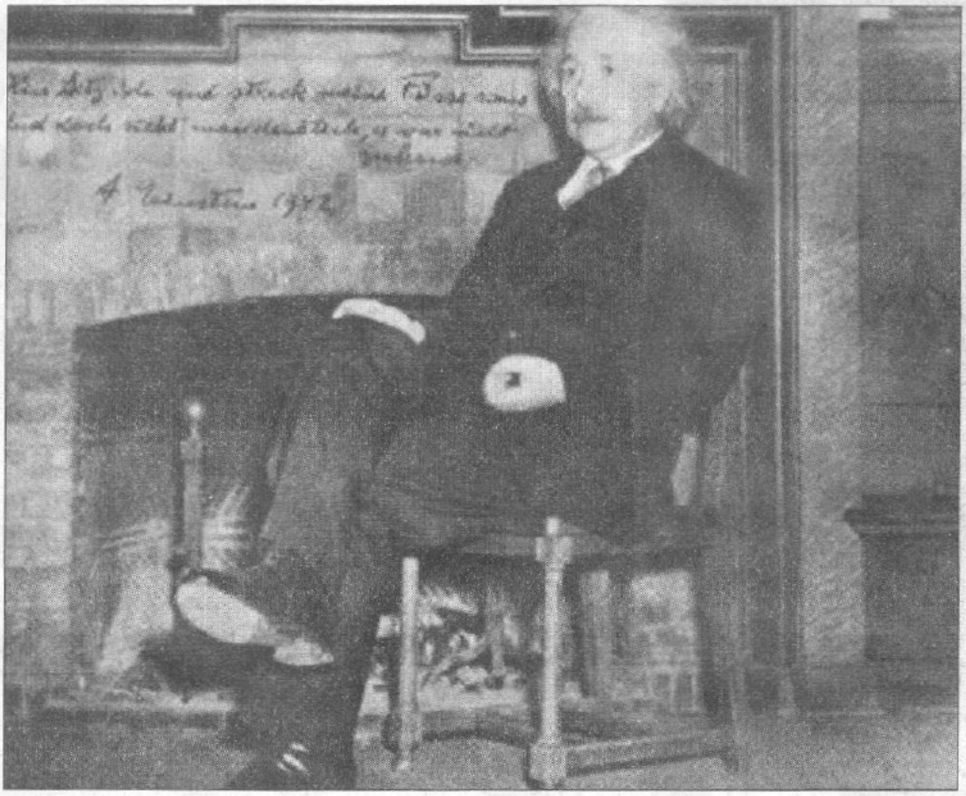
By Dennis Overbye



history back to the first micro-micro second of unrecorded time, the cosmological constant has been a trapdoor in the basement of physics, suggesting that at some fundamental level something is being missed about the world.

In an article in *Reviews of Modern Physics* in 1989, Steven Weinberg of the University of Texas referred to the cosmological constant as "a veritable crisis", whose solution would have a wide impact on physics and astronomy.

and physicist. A year after his visit with Hubble, Einstein threw his weight, along with de Sitter, behind an expanding universe without a cosmological constant.

But the cosmological constant lived on in the imagination of Lemaitre, who found that by judicious application of lambda he could construct universes that started out expanding slowly and then sped up, universes that started out fast and then slowed down, or one that even began expanding, paused, and then resumed again. This last model beckoned briefly to some astronomers in the early 1950s, when measurements of the cosmic expansion embarrassingly suggested that the universe was only two billion years old — younger Earth. A group of astronomers visited Einstein in Princeton and suggested that resuscitating the cosmological constant could resolve the age discrepancy.

Einstein turned them down, saying that the introduction of the cosmological constant had been the biggest blunder of his life. George Gamow, one of the astronomers, reported the remark in his autobiography, *My World Line*, and it became part of the Einstein legend. Einstein died three years later. In the years

energy on atoms had been detected in the laboratory, as early as 1948, but no one thought to investigate its influence on the universe as a whole until 1967, when a new crisis, an apparent proliferation of too many quasars when the universe was about one-third its present size, led to renewed muttering about the cosmological constant.

Jakob Zeldovich, a legendary Russian theorist who was a genius at marrying microphysics to the universe, realized that this quantum vacuum energy would enter into Einstein's equations exactly the same as the old cosmological constant. The problem was that a naive straightforward calculation of these quantum fluctuations suggested that the vacuum energy in the universe should be about 118 orders of magnitude (10 followed by 117 zeros) denser than the matter. In which case the cosmological constant would either have crumpled the universe into a black hole in the first instant of its existence or immediately blown the cosmos so far apart that not even atoms would ever have formed.

The fact that the universe had been sedately and happily expanding for 10 billion years or so, however, meant that any cosmological

Things got even more interesting in the 1970s with the advent of the current crop of particle physics theories, which feature a shadowy entity known as the Higgs field, which permeates space and gives elementary particles their properties. Physicists presume that the energy density of the Higgs field today is zero, but in the past, when the universe was hotter, the Higgs energy could have been enormous and dominated the dynamics of the universe.

In fact, speculation that such an episode occurred a fraction of a second after the Big Bang, inflating the wrinkles out of the primeval chaos — what Turner calls vacuum energy put to a good use — has dominated cosmology in the last 15 years. "We want to explain why the effective cosmological constant is small now, not why it was always small," Weinberg wrote in his review. In their efforts to provide an explanation, theorists have been driven recently to talk about multiple universes connected by spacetime tunnels called wormholes, among other things.

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been steadily and happily expanding for 10 billion years or so, however, meant that any cosmological constant, if it existed at all, was modest. Even making the most optimistic assumptions, Zeldovich still could not make the predicted cosmological constant to come out to be less than a billion times the observed limit.

Ever since then, many particle theorists have simply assumed that for some as-yet-unknown reason the cosmological constant is zero. In the era of superstrings and ambitious theories of everything tracing

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The flavour of the crisis was best expressed, some years ago at an astrophysics conference by Wilczek. Summing up the discussions at the end of the meeting, he came at last to the cosmological constant. "Whereof one cannot speak, thereof one must be silent," he said, quoting from Ludwig Wittgenstein's *Tractatus Logico-Philosophicus*. Now it seems that the astronomers have broken that silence. — ***Dawn\New York Times Science Service*** ■

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