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# Einstein's Greatest Blunder

**The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Universe.** *By Robert P. Kirshner, Princeton University Press, Princeton and Oxford, 2002, 320 pages, $29.95.*

BOOK REVIEW

*By James Case*

It might be said in retrospect that two notable events signaled the birth of modern cosmology. The first was Einstein's realization in 1917 that his newly minted "general theory" could accommodate either an expanding or a contracting universe, but not one of constant size. Because the leading astronomers of the time assured him that the Milky Way—then thought to constitute the entire universe—showed no sign of expansion or contraction, Einstein amended his field equations to include a "cosmological constant" $\lambda$ (later changed to $\Lambda$) to accommodate a static universe. He later described $\Lambda$ as his "greatest blunder," the one that cost him an opportunity to predict the second seminal event in the history of modern cosmology—Edwin P. Hubble's 1929 announcement that the universe is indeed expanding.

Astronomers were obliged to conclude, between 1917 and 1929, that the universe extends far beyond the limits of our own Milky Way. Improved telescopes revealed that what had formerly been taken for individual stars were in fact distant galaxies, comparable in size to the Milky Way. It is currently estimated that galaxies number in the billions. Most contain Cepheids, stars whose color and brightness vary periodically. Because such stars are plentiful in the Milky Way, where their distances from Earth can be determined by elementary methods, it was quickly established that their brightnesses are proportional to the lengths of their periods. Hence, the distances to nearby galaxies are inversely proportional to the squares of the brightness of the Cepheids contained in them. Moreover, the speeds of other galaxies relative to Earth can be determined from their redshifts, permitting astronomers like Hubble to plot the speeds of other galaxies against their distances, as shown in Figure 1.

A parsec is a unit of distance equal to about 3.25 light years. Kirshner points out that the indicated slope exceeds the currently accepted figure of about 70 kilometers per second per megaparsec by a factor of at least seven. Hubble diagrams show the universe to be expanding, with all but a few of the nearest galaxies moving away from Earth and (almost certainly) from one another. The simplest picture consistent with such a diagram involves individuals $1, \ldots, n$ who begin, at time $t = 0$, to move away from a common starting point $O$ with constant velocities $\mathbf{v}_1, \ldots, \mathbf{v}_n$. The distances between $i$ and $j$ at times $t > 0$ will then be $s_{ij}(t) = \|\mathbf{v}_i - \mathbf{v}_j\| t$. Hence, each of the $n(n-1)/2$ ratios $s_{ij}(t)/\dot{s}_{ij}(t)$ will equal the elapsed time $t$ since departure from $O$. If the individuals are galaxies, then $t$ represents the time elapsed since the "big bang." The fact that the ratios so obtained are roughly equal is deemed to support (by failing to contradict) the big bang theory.

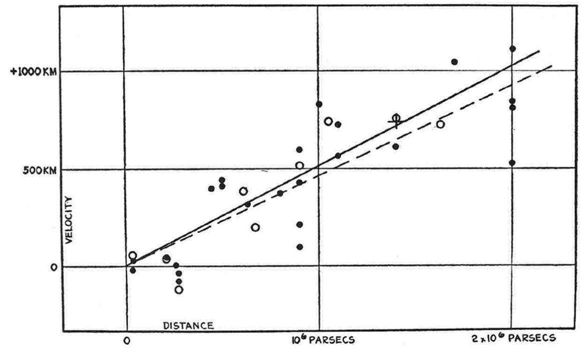

**Figure 1.** *The original Hubble diagram. Figures from* The Extravagant Universe.

Kirshner hastens to explain, however, that the foregoing picture is misleading, since it suggests that the big bang took place at a specific location. Of this there is no evidence. A more accurate picture, he writes, would resemble a vast three-dimensional jungle gym modeled on an infinite cubic lattice and constructed of (ramrod-straight) growing bamboo. Then every node (indeed, every location) in the lattice would be moving away from every other, and no location could legitimately be described as stationary. By this view, the big bang is merely the instant at which every segment of the bamboo framework commenced (simultaneously) to grow. Had he been addressing a more sophisticated audience, he might have likened the universe to the expanding surface

$$x^2 + y^2 + z^2 + w^2 = s^2t^2$$

in 4-space, where $s$ is a (roughly constant) rate of expansion. Every point on such a surface has the familiar three degrees of spatial freedom, and every point is moving away from every other, as Hubble observed for the universe. Yet no point can legitimately be called fixed.

Much of modern cosmology consists of a series of attempts to construct and interpret more accurate Hubble diagrams. Kirshner has written an entertaining and informative history of those attempts, with emphasis on the one of which he himself was a leader. The results obtained seem to indicate that the universe is not only expanding—as Hubble concluded—but is doing so more rapidly now than in the past. This utterly unexpected result was obtained almost simultaneously by Kirshner's "High-$Z$" team and by a rival group from the Lawrence Berkeley National Laboratory during the summer of 1998. Both teams proceeded on the assumption that the most accurate estimates would be obtained by observing supernovae (aka exploding stars) rather than Cepheids, since exploding stars are the brightest objects in the night sky and can be seen from farther away.

*Z*, incidentally, is the symbol used by astronomers to denote redshift. It is defined by the equation

$$\text{(frequency observed)/(frequency emitted)} \\ = 1 + Z\,.$$

How, one wonders, are mere Earthlings to know what frequencies of light were emitted billions of years ago by exploding stars that, even then, were nowhere near the eventual site of their still unborn planet? The task is simplified by the fact that one stellar explosion looks a lot like another.

It is currently estimated that typical galaxies host stellar explosions about once per century. More than a million of the billions of galaxies in the universe should therefore contain an exploding star in any given month. And since stellar explosions tend to last (shine with at least half their maximum brightness) for two to three weeks, significant numbers of exploding stars should be visible at any given time. Present methods allow astronomers, by examining thousands of galaxies, to find dozens of supernovae in a single year. So it is hardly surprising that substantial numbers of them have been studied in detail, with the full power of modern spectroscopy and diagnostic software.

*Not surprisingly, the discovery that the universe is expanding at an increasing rate is breathing new life into formerly obscure theories meant to explain the observed phenomena with fewer (and less heroic) assumptions.*

Supernovae come in two basic flavors. Massive stars tend over time to develop hot, heavy iron cores. When the core temperatures approach three billion degrees Kelvin, the iron nuclei within start breaking down, absorbing energy as they do so, in accordance with the accepted (earthbound) laws of nuclear physics. The absorption diminishes the core's internal pressure, permitting it to shrink gravitationally. So strong does gravity become in such high concentrations of mass that the shrinkage becomes an implosion. Within a second or two, the core accelerates inward to about a third of the speed of light. Then, as the rapidly concentrating mass approaches the density of an atomic nucleus, the strong nuclear force asserts itself, bringing the contraction to an abrupt halt and causing a shock wave to travel back upstream, ejecting the outer layers of the star (along with a hail of neutrinos) into outer space in what is called a type II supernova (SN II). What is not ejected stays behind to form a (massive) neutron star.

Smaller stars—under about 1.4 solar masses—are incapable of forming iron cores and must explode in other ways. Evidence suggests that stars of modest mass evolve more or less as our own sun is expected to do, exhausting its nuclear fuel, expanding into a red giant, then shrinking to a white dwarf. When the carbon and oxygen inside a white dwarf at last begin to fuse, the heat given off naturally increases the rate of fusion, eventually generating a "nuclear flame" that spreads rapidly throughout the dense little star. For a few weeks, the diminutive object burns as brightly as four billion suns. That's the event we see as a type I supernova. Strictly speaking, type I supernovae are now described as type Ia supernovae (SN Ia's), to distinguish them from aberrant type II supernovae that—although caused by the gravitational collapse of massive stars—give off light si-milar to that from SN Ia's. The aberrant type II supernovae are now described, for historical reasons, as type Ib supernovae (SN Ib).

The last SN Ia in the Milky Way was observed by Tycho Brahe on November 11, 1572. While taking a predinner stroll on his private island off the coast of Denmark, the youthful (and still unknown) astronomer was astonished to behold overhead—not far from the constellation Cassiopeia—a brilliant but wholly unfamiliar star. Only when assured by "country people passing in carriages" that they could see it too did he dare to believe his eyes.

If all supernovae were identical, they would furnish an ideal method for constructing accurate Hubble diagrams. By determining the speed and distance of each new supernova from its redshift and apparent brightness, it would be possible to determine the approximate speed and distance of the host galaxy. Multiple supernovae from a single galaxy would of course yield different estimates, due to the different positions and velocities of the individual supernovae within that galaxy. Yet such effects should be negligible for distant (and presumably heavily redshifted) galaxies. The task facing the High-*Z* and LBL teams was to correct for the fact that—although similar—even type Ia supernovae are by no means all the same.

The first and most obvious step toward standardization was to ignore all SN II's, including those of type Ib. The second was to learn enough about the physics to convert readings obtained from many different type Ia supernovae into standardized readings, as if some single "standard candle" had occupied each of their respective positions in phase space. This was done during the 1970s and 1980s, despite the difficulty of obtaining funding for a project unlikely to bear fruit before the Hubble Space Telescope could be launched in 1990. Kirshner attributes his own success in this endeavor to the willingness of relevant funding agencies to allow rival groups employing similar techniques to embark on a common mission.

The requisite standardization was achieved by observing that SN Ia's progress rapidly to maximum brightness, then dim at a slower—and relatively constant—rate for many months. Moreover, the brighter ones tend to dim more rapidly than the rest. So, by plotting the observed brightness of nearby SN Ia's against time, and analyzing the resulting "brightness curves," Kirshner's cohorts learned to deduce the actual from the observed peak brightness of a newly discovered SN Ia, and to refine their distance estimates accordingly. That is how the data points plotted in Figure 2 were obtained. The data fail to support the expectation that the rightmost points in a Hubble diagram should lie somewhat below the straight line best fitting the leftmost, as if the universe were expanding at a declining rate. The fact that the rightmost points lie above instead of below the middle path suggests that the nearer SN Ia's (which exploded more recently than the rest) were receding more rapidly from Earth at the time of their (relatively recent) explosions than were the latter at the time of their (much earlier) explosions. This makes no sense at all unless the universe is expanding more rapidly now than it used to be.

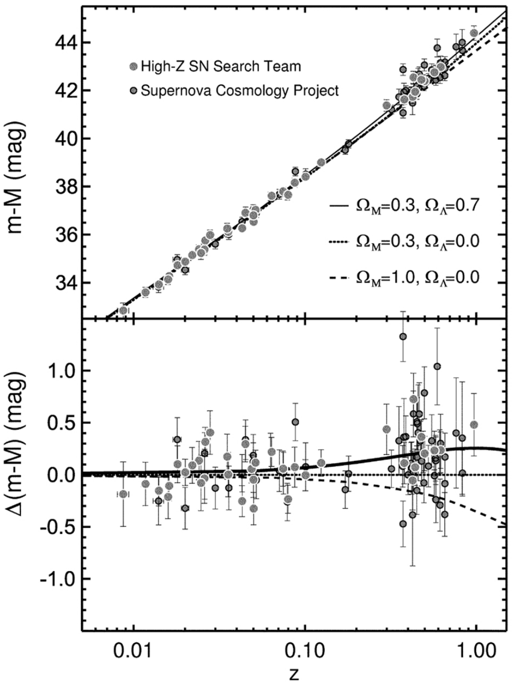

**Figure 2.** *The Hubble diagram for high-redshift supernovae.*

All this caused a sensation among cosmologists. Many now speak of a "Hubble flow," which appears to be dispersing large quantities of dark (unobserved) matter *and dark (unobserved) energy*, along with the heavenly bodies, ever outward to an unknown fate. Kirshner exhibits a pie chart suggesting that mass/energy in the universe currently consist of 60% dark energy and 30% dark matter, so that no more than 10% of the universe can be composed of ordinary matter (mainly protons and neutrons). These (dark and seemingly undetectable) forms of matter and energy are beginning to sound suspiciously like the massless/colorless "luminiferous aether" postulated during the 19th century to explain the transmission of light through empty space. Perhaps dark matter and dark energy are but attributes of a different sort of aether that is, at this very moment, being rarefied by the so-called Hubble flow.

Not surprisingly, the discovery that the universe is expanding at an increasing rate is breathing new life into formerly obscure theories meant to explain the observed phenomena with fewer (and less heroic) assumptions. One such theory—known as MOND,* for modified Newtonian dynamics—was proposed back in 1983 by Mordehai Milgrom, now at the Weizmann Institute of Science in Rehovot, Israel. MOND begins with the hypothesis that force is only approximately a bilinear function of mass and acceleration. Whereas the Newtonian hypothesis seems valid as it applies to familiar motions here on Earth, it appears to overstate the forces that act on slowly accelerating systems. By correcting for the diminished effects of very slow acceleration, MOND purports to account for the new data without postulating the existence of dark matter and dark energy.

Whether or not his and other mainstream interpretations of the new data survive the test of time, Kirshner has written a readable, entertaining, and informative account of an ancient and familiar—yet newly reinvigorated—branch of science.

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*A brief bibliography for MOND can be found in *American Scientist*, Vol. 91, No. 1, 2003, page 25.