The Texas Symposium on Relativistic Astrophysics

In every even-numbered year for the past quarter century, physicists, astronomers, and cosmologists have eagerly devoted a week of their winter holidays to the biennial Texas Symposium on Relativistic Astrophysics. This past year was no exception: the week of 14 through 19 December 1986 saw some 550 participants gathered in downtown Chicago for symposium number 13. (The name "Texas" refers to the location of the first meeting in 1962.) As always, the discussions ranged widely, and defied any simple summary. In the following, however, Research News presents a sampler:

Keeping Current with Cosmic Strings

Cosmic strings, which had already emerged as particle physics' most entertaining contribution to cosmology, have now taken on a whole new dimension: superconductivity. Recent calculations suggest that these hypothetical filaments of energy would not only be infinitesimally thin (10^{-30} centimeter across) and incredibly massive (roughly 10^{22} grams per centimeter), but might also be capable of supporting supercurrents of up to 10^{20} amperes. If so, then cosmic strings emerging from the Big Bang might well have triggered vast explosions in the surrounding matter, leaving the galaxies to form in exactly the kind of foamy, bubble-and-void structure that astronomers are finding today.

Princeton University physicist Edward Witten, who was the first to suggest that cosmic strings might be superconducting, reviewed the idea for conference participants in an invited lecture.

According to the grand unified theories of particle physics, Witten explained, certain quantum fields would have "frozen" within a microsecond of the Big Bang, thus forming a rigid configuration that serves as a kind of backdrop for the particle dynamics in the modern universe. (In technical terms, the rapidly cooling cosmic plasma broke the underlying symmetry of the field theory; the frozen entities are known as Higgs fields.) This process is mathematically analogous to the way water freezes into ice, said Witten, and a cosmic string is mathematically analogous to an imperfection in the crystal lattice—a thin, linear region where the frozen fields remain unfrozen.

Now, the key to the string's superconductivity lies with ordinary particles such as quarks or electrons, said Witten: a straightforward calculation shows that any particles falling into the unfrozen core of the string would proceed to move down the length of the string as if they were massless. Indeed, in the ultradense conditions right after the Big Bang, the string would have picked up a copious supply of such particles. Furthermore, said Witten, since most of these elementary particles carry electric charge, then any external force that happened to set more of them moving in one direction than in the other would produce an electric current. And finally, since the equations of relativity imply that massless particles must travel at precisely the speed of light—no more and no less—then such a current would continue to flow of its own accord, even after the external forces were removed.

Thus, superconductivity. The details of the process depend on one's precise assumptions about the particle physics, said Witten. But some models suggest that a cosmic string could support a maximum current of roughly 10^{20} amperes—a number so vast that one is immediately led to speculate about cosmological consequences.

These consequences likewise depend on one's assumptions about the early universe, said Witten. However, according to an analysis that he and his Princeton colleagues Jeremiah P. Ostriker and Christopher Thompson have recently published,* it is at least plausible that loops of superconducting string could have interacted with primordial magnetic fields and been boosted to a substantial fraction of their maximum current. Moreover, since the loops would have come out of the Big Bang in a furious state of vibration—any given segment of string would have been moving at roughly the speed of light—these supercurrents would have converted them into equally furious emitters of electromagnetic radiation. This radiation, in turn, would have impinged upon the ambient plasma and pushed it outward, leaving each loop surrounded by an explosively expanding shell of gas. Eventually, in fact, most of the ordinary matter in the universe would have been concentrated on bubble walls surrounding voids some 10 to 20 million parsecs in radius, while the loops inside the bubbles would have decayed away, having finally converted all their mass and energy into radiation. The universe would resemble a gargantuan mass of soapsuds. And in fact, noted Witten, that is exactly what recent surveys show: most of the galaxies—which presumably condensed within the shock fronts in this scenario—do indeed seem to lie in thin, sheet-like structures. Moreover, these structures surround large voids that are roughly the size predicted.

In sum, this superconducting string scenario is much more violent than previous

*J. P. Ostriker, C. Thompson, E. Witten, "Cosmological effects of superconducting strings," *Phys. Lett. B* **180**, 231 (1986).

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models of string-induced galaxy formation, in which the loops simply accrete matter by gravity. It is also highly conjectural, to say the least. Nonetheless, Witten and his colleagues point out that it does have two testable predictions. First, the bubble formation process should produce fluctuations in the 2.7 K cosmic background radiation of a few parts in 10^5 over a scale of a few arc minutes; observations are approaching that sensitivity now. Second, the nearest hot bubble that contains an electromagnetically live loop should be detectable as a radio synchrotron source at a distance of roughly 60 to 120 million parsecs; indeed, the radiating strings themselves may even be visible as gamma-ray sources at high redshift.

In any case, superconducting cosmic strings were widely discussed at the Chicago meeting, and have clearly caught the community's fancy. One striking example was a suggestion by George B. Field of the Harvard-Smithsonian Center for Astrophysics and Alex Vilenkin of Tufts University. Noting that the overall luminosity of a typical superconducting loop would be remarkably similar to that of a quasar (10^{49} ergs per second), and noting that most of the electromagnetic radiation from such a loop would be emitted in highly collimated jets, which are also seen in many quasars, they propose that quasars and superconducting strings are one and the same.

Exploring the Lyman-alpha Forest

When astronomers first discovered quasars in the early 1960s, and began to realize just how phenomenally bright and far away these objects really are, they were also quick to recognize a serendipitous opportunity: the very fact that the quasars could be seen across billions of light-years meant that they could also provide a unique probe of deep intergalactic space.

In the intervening two decades that promise has been amply fulfilled, said California Institute of Technology astronomer Wallace L. W. Sargent, who has himself been one of the leaders in this field. Even now, as he pointed out in an invited review talk at the symposium, the analysis of quasar spectra continues to provide important clues to the origin of galaxies and the distribution of mass in the universe.

A quasar's spectrum is typically redshifted as a result of the Hubble expansion by a factor of 2, 3, or even 4, Sargent said. For present purposes, however, the interesting region lies to the blue side of the redshifted Lyman-alpha emission line produced by hydrogen in the quasar. There, one invariably finds a host of very narrow, very densely packed absorption lines. First discovered in 1971 by Roger Lends of the Kitt Peak National Observatory, this phenomenon has come to be known as the Lyman-alpha "forest."

The obvious interpretation, said Sargent, is that each line in the forest represents Lyman-alpha absorption of the quasar's light as it passes through isolated clouds of hydrogen along the line of sight. And indeed, this interpretation is supported by several pieces of evidence:

- The absorption lines all lie on the blue side of the quasar's Lyman-alpha peak, which is exactly what one would expect from clouds that are closer, and therefore less redshifted, than the quasar.
- The absorption lines are distributed at random as a function of redshift, which would be very hard to explain if they were somehow associated with the quasar itself.
- Pairs of nearby quasars often show precisely the same absorption lines. Again, this is exactly what one would expect from extended clouds, but not from lines that originated in the quasars themselves.
- The very fact that a given cloud is less redshifted than the quasar means that the two objects are moving at a high relative velocity. Even quasars would have a tough time ejecting blobs of gas at those speeds.

A few of the absorption lines are comparatively strong, noted Sargent; they seem to arise from quasar light shining through the disk of an intervening galaxy that is too far away and too faint to be seen directly. But the vast majority of the absorber clouds are much smaller, he said. They typically contain about 10 million solar masses of hydrogen, as estimated from the strength of the absorption lines, and they typically measure about 8 kiloparsecs in diameter, as estimated from common absorption lines in neighboring quasars. In other words, they are barely the size of the smallest known dwarf galaxies. Indeed, they appear to be clumps of hydrogen gas that did not have quite enough mass to produce stars.

These low-mass clouds fit in nicely with the theorists' current ideas about "biased" galaxy formation, noted Sargent. The thinking is that galaxies only formed within the most massive clumps of material in the early universe, whereas gas within the less massive clumps remained quiescent and dark. Recent numerical simulations suggest that such a process would produce a universe much like the one we actually observe, with galaxies clustered along bubble-like shells—corresponding to the densest clumps of primordial matter —and with large "voids" of quiescent matter in between the ridges where galaxies simply never formed.

In this context, said Sargent, it is striking that the Lyman-alpha clouds are distributed at random, with no sign of this bubble-and-void structure. "It's certainly conjecturable that the clouds inhabit the voids," he said. Also consistent with the bias theory is that many of the clouds appear to have disintegrated over time: the absorption lines are much more numerous at high redshift—that is, when the universe was younger—than at low redshift. One plausible explanation for this phenomenon, said Sargent, is to assume that the clouds were originally immersed in a very hot, but very tenuous gas that held them together by exerting an inward pressure. (Much the same thing happens on a smaller scale within our own galaxy, where dense gas clouds are held together by a rarified interstellar medium.) Presumably this "intergalactic medium" was heated by radiation from the quasars themselves, or perhaps by some more exotic mechanism. But in any case, as the universe expanded the intergalactic medium would also have expanded, its pressure would have fallen, and the Lyman-alpha clouds would have dissipated.

One obvious question of great cosmological import is whether the Lyman-alpha clouds contain enough total mass to ultimately bring the expansion of the universe to a halt (or, more technically, to "close" the universe). The answer is no, said Sargent: at most, the clouds can only contribute about 1% of the necessary mass. So if the theorists want to follow their predilections for a universe that is precisely closed, they still have to postulate a universe filled with mysterious and unobservable dark matter.

New Variables for Quantum Gravity

In the long and frustrating effort to reconcile quantum mechanics with general relativity—Einstein's theory of gravity—nothing has been quite so frustrating as the nature of Einstein's equations themselves. For all their conceptual elegence in expressing gravity as the curvature of space and time, the equations are grotesquely nonlinear; as a result, their quantum analog—the "Schroedinger equation" for gravity—has never been solved.

Now, however, all that may be changing. A new set of mathematical variables recently introduced by physicist Abhay Ashtekar of Syracuse University has resulted in a great simplification of the equations.* Moreover, as Ashtekar's colleague Lee Smolin of Yale

*A. Ashtekar, "New variables for classical and quantum gravity," *Phys. Rev. Lett.* 57, 2244 (1986).

University explained at the symposium, they open up some intriguing new vistas on quantum gravity itself. For example:

■ Ashtekar's variables combine information about the curvature of space with information about the evolution of curvature in time. As a result, they transform Einstein's highly nonlinear equations into much more tractable quadratic equations. Indeed, the dynamics of gravity comes to resemble the dynamics of a simple harmonic oscillator—a system whose solution can be found in any elementary quantum mechanics text.

■ Ashtekar's approach depends heavily on the use of spinors, which are the natural mathematical structures for describing relativistic particles such as quarks, electrons, and neutrinos. Indeed, Einstein's equations in their new form are closely analogous to the so-called Yang-Mills equations, which are used in conventional particle physics to formulate the grand unified theories of the strong, weak, and electromagnetic interactions. The new variables may thus point the way toward physicists' Holy Grail: an even grander unification that incorporates all four forces.

■ In Ashtekar's formulation the quantum gravity equations can be solved, at least partially. The intriguing thing, as Smolin has shown in collaboration with Ted Jacobson of Brandeis University, is that the solutions can best be expressed in terms of integrals of the new variable around closed paths in space. Moreover, the dynamics of quantum gravity seems to involve the splitting and joining of these paths wherever they cross each other. The whole thing is eerily reminiscent of the splitting and joining that goes on in the currently fashionable theory of superstrings. Since superstrings are also supposed to describe quantum gravity (although not precisely Einstein's gravity), Ashtekar's variables may be pointing to a deep connection.

■ Finally, said Smolin, the fundamental geometric object in Einstein's theory—the so-called metric tensor—is an inherently quantum object in Ashtekar's formulation. Like position and momentum in ordinary quantum mechanics, it is subject to the uncertainty principle, and it can only be defined in terms of probabilities and averages. This means that, on the very smallest scales, the structure of space and time is subject to violent fluctuations. Indeed, said Smolin, on the smallest scales space and time may not *have* any well-defined structure. They may be more like a kind of "quantum foam." This idea has been around for many years, he added. But Ashtekar's formulation of quantum gravity may be yielding the first, mathematically precise definition of it. ■

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A New Wave of Enzymes for Cleaving Prohormones

Researchers have isolated several enzymes that snip peptide hormones from the inactive prohormones. Some may not stand the test of time

ALL peptide hormones and neurotransmitters are synthesized in large inactive "prohormones" that must be cleaved at specific sites to release the active agents. Although researchers have searched for many years for the enzymes that perform the cleavages, they have had little luck until recently. They have now produced what one investigator calls "an embarrassment of riches." Several proteases that appear to have the required specificities have been isolated and are vying for consideration as cleaving enzymes.

Most of these proteases are clearly different from one another, a diversity that may simply reflect the existence of distinct cleaving enzymes for different prohormones. Alternatively—and perhaps more likely—some of the isolated enzymes may be red herrings that do not actually participate in peptide hormone synthesis. Proving that an isolated protease is physiologically active in cleaving peptide hormones from prohormones, and not just one of the many cellular degradative enzymes, is very difficult.

The pattern in which physiologically active peptides are synthesized within larger prohormones has been highly conserved in evolution and is found in organisms as simple as yeast and as complex as man. In fact, the protease with the clearest claim to being a prohormone-cleaving enzyme was identified about 2 years ago in *kex2*, a yeast mutant, by Jeremy Thorner, David Julius, and their colleagues at the University of California in Berkeley. This enzyme cuts the yeast α-factor, a peptide that contains 13 amino acids and is necessary for sexual mating in yeast, from its precursor protein.

A great deal of evidence indicates that prohormones are converted to the active hormones in cells within the small membrane-enclosed vesicles called secretory vesicles. Because the cells of mammals and other higher organisms are not amenable to the same types of genetic analysis and manipulation that led to the discovery of the *kex2* enzyme, many investigators therefore try to improve their odds of coming up with physiologically important cleaving enzymes by purifying the secretory vesicles first and using them as a starting material for isolating the target enzyme. For example, Y. Peng Loh and her colleagues at the National Institute of Child Health and Human Development took this approach to look for enzymes that cleave pro-opiomelanocortin (POMC), a prohormone that is made in the pituitary gland and contains within its structure no fewer than seven active peptides.

The Loh group has isolated from the pituitary gland two POMC-cleaving enzymes that are at least very similar to one another and may be identical. According to

Several proteases that appear to have the required specificities have been isolated . . .

Loh, the enzymes cut POMC at the same three sites at which it is initially cleaved in the pituitary, which means that the proteases satisfy one of the criteria that must be met by authentic cleavage enzymes. Recent work indicates that the enzymes also accurately cleave proinsulin to insulin and provasopressin to vasopressin, findings that suggest that the enzymes may have a broader spectrum of activity in the body than was originally thought.

In the intermediate lobe of the pituitary, the products released by the initial set of three cuts are further split. Loh's enzyme is not capable of this second round of cleavages, however. This finding suggests that at least one additional enzyme is needed to convert POMC to its final products in the intermediate lobe.

A second criterion that must be met by a prohormone-cleaving enzyme is that it must be active at the pH of the secretory vesicles, which is generally taken to be somewhat acidic, around 5 to 6. The pH optimum of the POMC-cleaving enzyme is in the range of 4.0 to 5.0, Loh says, and it should therefore work in the vesicles. In addition, compounds that inhibit the activity of the