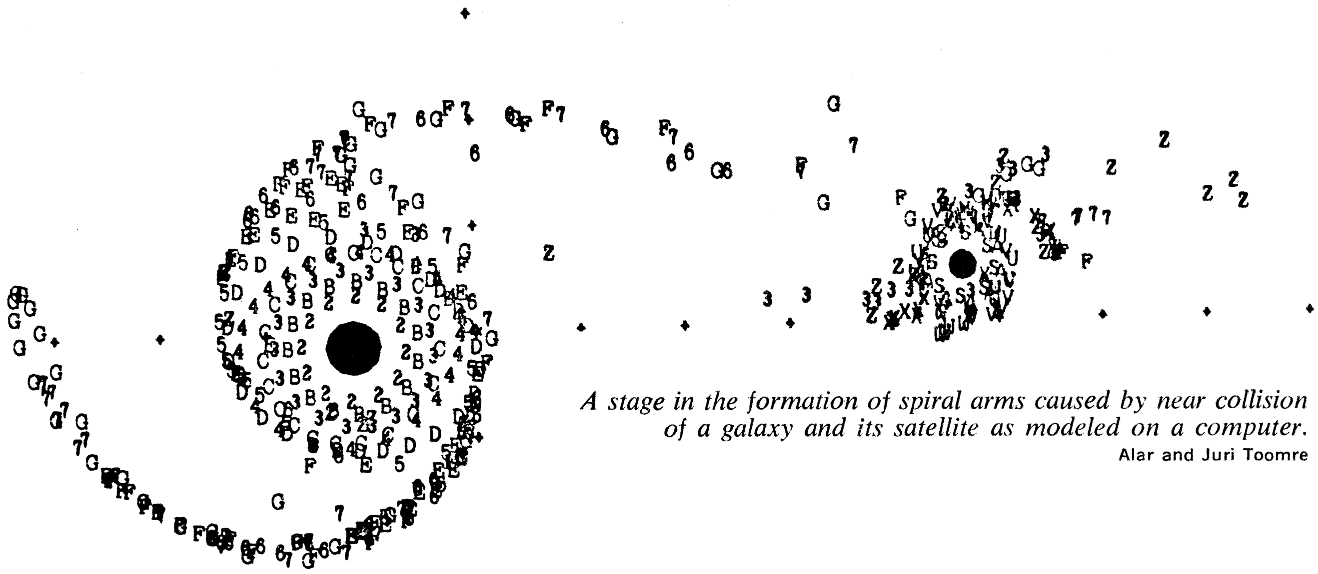


A stage in the formation of spiral arms caused by near collision of a galaxy and its satellite as modeled on a computer.
Alar and Juri Toomre

How the universe got its lumps

Cosmologists are developing hypotheses of how galaxies evolved and how they interact with each other

by Dietrick E. Thomsen

A universe that is smooth and even and the same in all directions is the easiest thing to imagine coming out of the big bang that many cosmologists suppose was the origin of the cosmos. It is also mathematically easier to deal with than a lumpy one. But it isn't the universe that we have. We have a universe with irregularities of structure: galaxies and clusters of galaxies. The irregularities make the universe as we know it.

The question of how the galaxies and clusters evolved is generating a good deal of heat and a lot of words among cosmologists. Some suppose that the big bang started out smooth, and that the expanding universe later developed turbulences and clumps that evolved into galaxies. Others suggest that the irregularities were there from the beginning. Still others put a reverse twist on the problem: If there were irregularities early on, they say, subsequent evolution should have smoothed them out instead of making them worse.

P. J. E. Peebles of Princeton University has long been a proponent of a smooth beginning and subsequent development of irregularities. At a symposium on cosmic evolution at the Coral Gables Conference on Fundamental Interactions at High Energy, held at the University of Miami in January, he described a computer simulation that began with 300 randomly placed mass points.

Each was endowed with a velocity directed radially outward from the center of the space they occupy. As this hypothetical model evolved with time, it developed clumps and irregularities. "It starts smooth and gets more and more messy," he says. A big-bang explosion would endow matter with straight line velocities; nobody can see how it would cause rotations. Peebles suggests that in early stages of the evolution the galaxies or the clumps that become galaxies overlapped and rubbed against each other. This could have started them turning.

Another important evolutionary question is where galactic magnetic fields came from. A possible answer, says Peebles, is that stars, which have understandable means of generating magnetic fields, expel puffs of field from time to time. The motion of the galaxy combs these fields out, so to speak. If this is true, he says, then there should be no net magnetic flux in the galaxy, just regions of one direction alternating with regions of the reverse direction. But radio astronomical observations show that there is a net flux. To say that the flux is primeval, that it was always there, raises the so-far-unanswered question, why? Peebles is not happy with it.

There are many other unanswered questions: Whether matter and antimatter are equal in the universe, whether the entropy of the universe is increasing, what is the origin and significance of the cosmic dust. "We're scratching for the big picture," says Peebles.

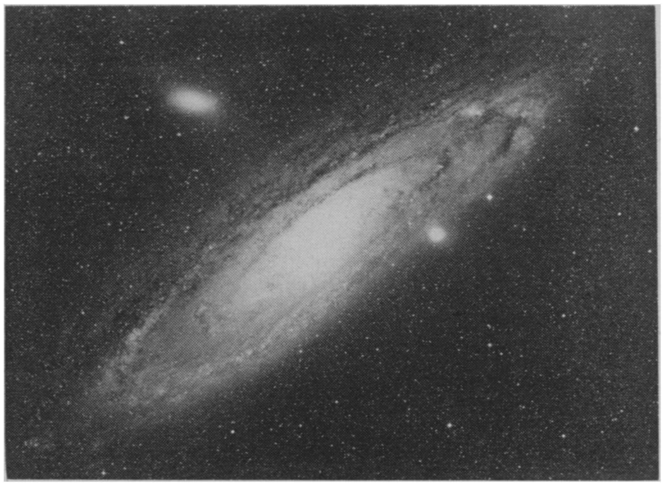
An important part of the big picture is whether the universe is open or closed. Will the expansion continue indefinitely or will it stop or even reverse some day? Put still another way, the question involves the shape of the three-dimensional universe: Is it an open curve, the three-dimensional analogue of a hyperbola, or a closed curve, the analogue of an ellipse?

The answer depends on the density of matter in the universe. If the universe, on the average, is dense enough, it will be bound together and closed by the mutual gravitation of its parts; if not, it is doomed to endless expansion.

There is not enough matter in the observed galaxies to bind the universe, but astronomers have long suspected that there is a lot of unseen matter. The stability of galaxy clusters has been cited as evidence of that. Various clusters of galaxies appear gravitationally stable although the galaxies do not seem to have enough mass to stick together. In the cluster in Coma Berenices, George Field of the University of California at Berkeley points out, the gal-

Hale Observatories

The Coma cluster: What makes it stick together?



Hale Observatories

A galaxy with spiral arms: The Andromeda nebula.

axies have only one-eighth the mass necessary to bind the cluster. Intergalactic gas is supposed to do the binding.

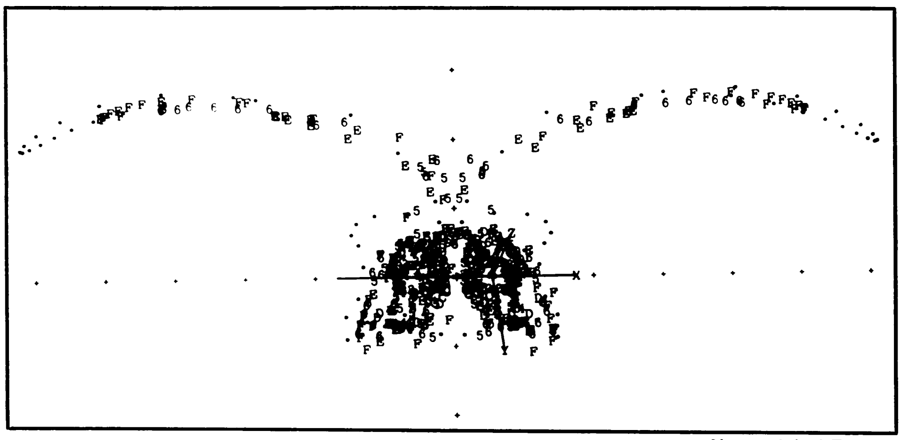
Recently the X-ray astronomy satellite Uhuru found an extended source of X-rays in the Coma cluster (SN: 1/29/72, p. 77), and this is supposed to be evidence of intergalactic gas there. Even if it is, says Field, his calculations of the probable spectra, temperature and density of such gas show it to be inadequate to bind the cluster. Likewise, gas of this sort pervading the universe could not bind the universe.

Field tried the known densities of mass for various classes and combinations of classes of objects in the universe—galaxies, stars, interstellar gases, elementary particles, electromagnetic radiation—and found none really adequate to close the universe.

There could still be hidden mass. There are also some other suggestions of how to close the universe, some of them slightly kooky. If the people who believe that turbulences were present in the original big bang are right, says Field, much of the energy of expansion would be converted to gravitational waves, and they could have sufficient density to bind the universe. They would also have another consequence: The galaxies would jiggle back and forth with the crests and troughs of these waves. Experimental tests to see if such ideas may be correct might be done in the next few years, Field speculates.

Another possibility is that Newton may have been wrong. "But we know he wasn't," says Field. The most important corrections that the modern theory of general relativity makes in Newton's work amount to one part in a hundred thousand. Some people suggest that perhaps the graviton, the particle that is supposed to carry gravitational forces between bodies, has a finite mass instead of none at all. This would give gravity a finite range instead of the infinite range it is supposed to have. A graviton mass of 10^{-38} grams would give a range of one megaparsec (3.26 million light-years). If you want to close the universe with less mass than current theory requires, you have to change gravity somehow. But this is not the way to do it, says Field; this way requires more mass.

Suspicions that Newton was wrong have also been entertained by people concerned with the interactions between galaxies. There are many instances in which galaxies appear to be somehow interacting with each other: Two nearby galaxies are seen to be connected or nearly connected by a bridge of luminous matter. In other cases galaxies appear to have thrown out tongues or loops of matter. The mass involved in these phenomena is enormous, and some people have supposed that gravity was too slight a force to accomplish the disruptions. Something new and exotic must be at work.



Alar and Juri Toomre

Two colliding galaxies cause each other to throw out long tongues of matter.

Not so, says Alar Toomre of the Massachusetts Institute of Technology. Gravity can do it all very well. At the Miami meeting, Toomre apologized for dealing with such an old-fashioned 18th century subject as tides in a conference devoted to the latest reaches of the most up-to-date theoretical physics. But tides are essentially what these phenomena are.

Toomre, working with his brother Juri Toomre, has made computer models of what happens as two galaxies pass near each other at various distances and in various relative directions. They have made movies of these, a kind of cosmological time-lapse photography that condenses eons into seconds. "Here goes the Precambrian, the Paleozoic, the Mesozoic," Alar Toomre said as the movie frames flickered by. The work has produced evolutionary models whose final stages approximate several situations that are actually seen.

The chances are of course small that two unrelated galaxies might collide, but there are numerous instances of one galaxy being the satellite of another, and in such cases close passages can be predicted. Alar Toomre hastens to say that he does not suggest that all spiral arms of galaxies can be explained in this way. Many must come from internal happenings in galaxies, but some come from collisions, he says.

All in all it appears that gravity is the only major force operating cosmologically and that cosmologists will have to figure out the evolution of the universe on its terms. □