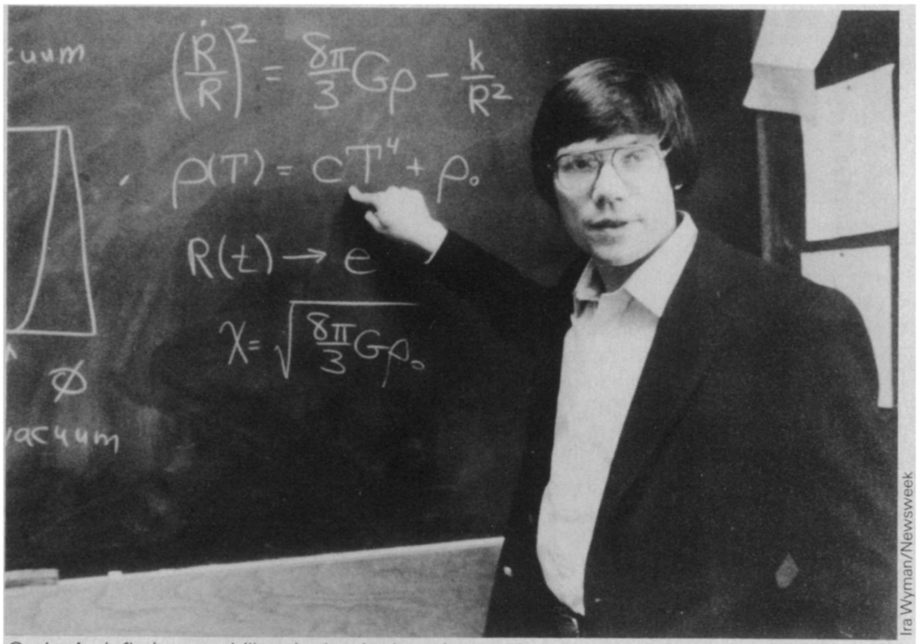
The New Inflationary Nothing Universe

Particle physicists are bringing symmetry to cosmology — a symmetry that seems to be turning out to be a null balance

By DIETRICK E. THOMSEN

Cosmology started out as a branch of astronomy. Lately it seems to be becoming a branch of particle physics, or at least a meeting and commingling place of astronomy and particle physics. If a dinner-table conversation at the recent Eleventh Texas Symposium on Relativistic Astrophysics (held in Austin) is any indicator, some of the traditional astronomer cosmologists resent the invasion of the particle physicists. But as Alan H. Guth of Massachusetts Institute of Technology pointed out in a talk at the same meeting, particle physicists have nowhere else to go.

The theorists of particle physics have made much progress toward a theory that would unify most of that science, but in so doing they have left the realm of practical experiment behind. To test the several candidates proposed to be *the* Grand Unified Theory (GUT), physicists have to study phenomena that occur at fantastically high energies. There is no hope of producing such energies in a laboratory. As Guth remarks, it would take "a linear accelerator one light-year long — unlikely to be funded during the Reagan administration." The only place to find such energies is in the early stages of the history of the universe, and so numbers of particle physicists are landing in cosmology.



Ira Wyman/Newsweek

Guth: An inflationary chill at the beginning of cosmology.

They hit the ground running. The application of what Guth calls the simplest of the GUT theories, the one based on the mathematical symmetry group SU(5) and proposed by Howard Georgi and Sheldon Glashow, produces radical changes in cosmology. The standard astronomically derived big-bang theory has the universe expanding smoothly, causally and adiabatically from the moment of origin to the present time. (Adiabatic cooling is a drop in temperature due to expansion alone without loss of heat from the system.) GUT cosmology rejects this, proposing that the universe in its very early stages went through one or more phase transitions (like a freeze or onset of boiling), and that these transitions interrupted causality and adiabatics.

Another "dramatic difference from earlier cosmology," in Guth's words, is that GUT cosmology seems to be a theory of creation truly *ex nihilo,* and the universe seems to remain perpetually nothing as long as it exists. That is, all of the quantities that are the subjects of conservation laws and so important to a physical analysis of the system (such as electric charge, angular momentum, "color" charge, etc.) seem to be so arranged that negative and positive amounts of them are equal and so always add up to zero, a situation "you can't distinguish from nothing," Guth says.

(Guth also says that he has been trying to persuade his colleagues to start abbreviating "theory" with Th instead of just T. If they do, it would be tempting to call this the world according to GUTh.)

GUT cosmology has three main consequences. It predicts first that there was one or more phase transitions at a time when the temperature of the universe was 10^{14} billion electron-volts (10^{14} GeV). In Guth's use of units 1 GeV is about the equivalent of 10^{13} kelvins, so in kelvins that temperature comes out to 10^{27} compared to the universal mean temperature of about 3 kelvins at present.

The second prediction is that magnetic monopoles exist (SN: 11/27/82, p. 348; 12/4/82, p. 362) and that their mass is about 10^{16} GeV. In Guth's units this equals about a hundred-millionth of a gram. The third consequence is that the law of conservation of baryons no longer holds. Baryons are a class of particles whose lightest member is the proton. They include the neutron and several dozen heavier, radioactively unstable varieties. The baryon conservation law, the proposition that the net number of baryons and antibaryons never changes (which means that baryons change into other baryons when they do change), was a pillar that held up the roof of the older particle physics and the older cosmology.

Application of the new particle physics to cosmology deals in particular with three serious problems, the horizon problem, the flatness problem and the magnetic monopole problem. Under the assumptions of the standard big-bang theory — that is, the old cosmology — the universe in its earliest moments expands too fast to maintain causal relations. The speed of light is too slow for messages to catch up, and different parts of the universe get out of communication with each other. However, at the present time we observe a high degree of isotropy in the universe: things are very much the same in all directions. That tells us that all parts of the universe were in communication with each other throughout the expansion or at least through as much of it as serves to determine present conditions. Or, in other words, an unbroken chain of causes stretches back from now to the origin. The incompatibility between the two statements is the horizon problem.

Our present observation tells us also that space is very nearly flat. Any curvature that there is must be minute. In the standard model, the universe tends to evolve toward greater curvature, so if it is very flat now, it must have been that much flatter in the earliest times. This is an extremely special initial condition, and its happening just at random is highly improbable.

The creation of magnetic monopoles is governed by the topology of space-time at the moment they come into existence. One monopole is made in each volume of space of a certain critical size. The size of the volume is governed by a critical length, called in technical terms the coherence length of the Higgs field. (The Higgs field is an important mathematical link in the unification of the different force fields that we observe, electromagnetic, nuclear, etc., into a single overall description. Its coherence length is the maximum distance over which phenomena that arise from it can propagate themselves without getting out of phase.) Under the ordinary big-bang assumptions the Higgs coherence length is very short. The universe contains an astronomical multitude of such critical volumes, and a corresponding number of monopoles is made.

Monopoles are extremely massive for elementary particles. Such a large number of them would make the density of the universe extremely high. The high density speeds up the adiabatic cooling rate and so the evolution of the universe. The universe could go from the big bang to its present state in 30,000 years. Such a number is a blatant contradiction of evidence from several branches of science.

Guth and the other proponents of the new inflationary model contend that the insertion of a phase transition at a very early split second of history can cure these problems. (The possibility of such a happening is closely connected to the repeal of the law of baryon conservation by the GUT theory.) A phase transition is a sudden change of structure and order of a material system. Water undergoes a phase transition when it freezes or boils. In physics since Einstein, space-time has quasimaterial properties, and it can go through an analogous change. The universal phase transition occurs during a super-cooling period, an era when the universe cools much faster than the ordinary rate. The physicists speak of bubbles of the new phase appearing in the midst of the old, like bubbles of steam in boiling water. The bubbles grow and coalesce until all of space-time has changed to the new phase just as all the water in the pot eventually becomes steam.

The phase transition cures the horizon problem by legitimizing the interruption of causal relations. During it the different parts of the universe are not in communication with one another. After the phase transition is complete, the universe cools adiabatically, and the conditions we have now derive from those that obtained immediately after the phase transition. Thus, the initial conditions of the universe do not determine our current state. In fact, during the transition the universe actually expands at an exponential rate, faster than the simple adiabatic rate, but that no longer matters. Causal connections do not have to be preserved during that period. It is this extrafast expansion that contributes the word "inflationary" to the name of the new model.

When the general relativistic equations that describe space curvature are calculated in connection with the phase transition, it turns out that the phase transition requires a very flat space, and so expansion to the present state had to start from a very flat configuration. This solves the flatness problem. The phase transition solves the monopole problem by changing the topology so that only one monopole per universe or fewer appears.

The phase transition provides also for creation *ex nihilo*. In the language of mathematical field theory the phase transition can be seen as a change from a false vacuum to the true vacuum. "Vacuum" in this terminology means the zero energy level of the system, a state devoid of matter or energy. Any real phenomena in the system exist at energy levels above the vacuum, and all dynamical processes take place between these higher energy levels.

Energy scales are relative, and it turns out (though it seems very strange) that the zero, vacuum, levels at different stages in the history of the universe can be different. If so, only the lowest possible one of these is the "true vacuum." The others are "false vacuums," and in any era when dynamics is based on a false vacuum, a catastrophe may occur in which the bottom falls out, so to speak, and dynamics shifts to base itself on the true vacuum. The phase transition is such an occurrence. It is not so much that nothing somehow becomes less than nothing as that the range of something is increased. Phenomena that were not possible before can now appear.

Among the new phenomena that appear at this point, Guth says, are those that make our universe recognizably what it is: energy, entropy and matter. It can be said, therefore, that the false vacuum is the source of energy, entropy and matter as they arise somehow from its disappearance. Since the false vacuum is by definition nothing, it follows that these things come from nothing.

The original inflationary universe model, however, does not solve another important cosmological problem, that of homogeneity. Cosmologists believe that on the large scale the matter and energy in the universe are spread around evenly. (There are some recent astronomical observations that raise questions about this belief, but until there is a solid disproof of it, homogeneity will remain a basic input into cosmological theories.) To get homogeneity in the inflationary-universe model, the bubbles that form in the phase transition must grow and coalesce in the proper way so that everything mixes together evenly. It turns out they do not.

This difficulty seemed insuperable until, after some cogitation, it was realized that only one bubble is enough, the one we are in. This bubble represents as much of the universe as we can observe, and within it we can have homogeneity. Why should we concern ourselves with what lies outside it? With this the "new inflationary universe" model was born.

"The details are still not quite right," says Guth. There are in fact still some serious difficulties in fitting the theory to observations. "We are still looking for one theory to solve all problems," he says, but he is hopeful that this is the right way to go. And if so, there we will be, ensconced in our bubble in a universe that comes from nothing or almost nothing. And Guth concludes, "The universe itself may be the ultimate free lunch." □