From fireball to galaxies: Making late waves

How a universe that started out as a hot, dense fireball developed an intricate structure consisting of galaxies, clusters of galaxies, voids and other large-scale features is one of the major conundrums in cosmology today. Theorists believe that at some point after the Big Bang, fluctuations in the smooth flow of matter and energy served as seeds for galaxy formation. The question is when and how those fluctuations occurred. A new theory postulates that these fluctuations happened much later than suggested by previous models.

All models for generating fluctuations on a cosmological scale require a phase transition — a change in the fabric of space itself to produce lumps and ripples in the distribution of matter. Such density fluctuations eventually yield the galaxies and galaxy clusters now observed.

David N. Schramm of the University of Chicago and his collaborators suggest that such a phase transition occurred a million or so years after the Big Bang rather than during the first nanosecond of the universe's life. "Before, people always thought phase transitions had to be early, and then they were stuck with a particular mode of thought," Schramm says. "Allowing the phase transition to be late opens up all sorts of new possibilities." He and his colleagues describe their theory in the April Comments on Nuclear and Particle Physics.

When water freezes to form an ice cube, different parts often freeze at slightly different rates. These separately formed regions of ice don't quite mesh to create a perfect crystal. Consequently, an ice cube often shows internal imperfections, usually seen as fractured lines and planes. Similarly, a phase transition on a cosmological scale would produce "topological" defects in the vacuum of space. The universe's lumpiness would arise much in the same way frosty white planes appear within ice cubes.

Schramm and his colleagues base their arguments for a late phase transition on the possibility that neutrinos — subatomic particles normally thought to have no mass at all — may actually have a tiny mass. That mass would manifest itself about a million years after the Big Bang. Such a neutrino mass, about one fifty-billionth that of an electron, would also help account for why the sun produces fewer neutrinos than expected according to conventional theories (SN: 4/30/88, p.277).

The idea of a late phase transition is appealing because such a change occurs after electrons combine with protons to produce hydrogen atoms and the amount of energy in the form of electromagnetic radiation, or photons, stabilizes. This means a late phase transition has practically no effect on the microwave background radiation, which pervades the universe and appears uniform in every direction. Theories in which phase transitions happen earlier have a great deal of difficulty explaining how fluctuations can grow to become seeds for galaxy formation without distorting the microwave background radiation to a greater extent than observed.

"In our model, we avoid making fluctuations in the background radiation while still making fluctuations that would produce galaxies," Schramm says. "The seeds of galaxy formation are created at the time the galaxies need them, not before."

Measurements of any slight distortions in the microwave background radiation would provide one of the best tests of the new model, Schramm says. The less distortion observers detect, the more promising a late-phase-transition model looks.

Computer simulations also provide a useful check on the model. Recently, David N. Spergel of Princeton (N.J.) University and William H. Press of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., investigated one particularly simple case to see if a late phase transition involving neutrinos would evolve into the kind of structures observed in the universe.

"In its simplest form, it doesn't look too promising," Spergel says. "However, many other variations are possible. A lot of work needs to be done to explore the model and see if it provides a viable alternative for galaxy formation."

Furthermore, a neutrino phase transition isn't the only possibility. "Once we recognized that this particular transition could do it, we realized that particle physics offers other possibilities for a late phase transition," Schramm says. "We need to look at other kinds of particle models . . . that can yield the same kind of effect."

"Maybe something crazy is needed," says Princeton astrophysicist P. James E. Peebles. "None of the standard models for formation of galaxies and clusters of galaxies fits very well with all of the data. That could be because we're missing some elementary point in the way we approach the data, or it could be we're missing something big, like a late-time phase transition. I certainly wouldn't dismiss [that possibility], because we're getting a little desperate." *— I. Peterson*

Global smog: Newest greenhouse projection

Most forecasts of "greenhouse" climate changes focus on higher average land-surface temperatures and sea-level rises — changes that could blight crops and inundate coastal communities. But farmers and beachfront dwellers aren't the only individuals likely to suffer directly from greenhouse effects, scientists reported last week. New studies suggest a greenhouse warming could greatly exacerbate air pollution — especially smog-ozone levels — throughout the world.

At NASA's Goddard Institute for Space Studies in New York City, David Rind and his co-workers have begun tweaking the institute's computer model of climate to explore weather-related changes that might result from a doubling in atmospheric levels of carbon dioxide, the primary greenhouse gas. In general, the model anticipates a growing sluggishness in weather systems, Rind told a Washington, D.C., conference on climate and air quality sponsored by the Environmental Protection Agency and American Gas Association.

As climate warms, temperatures climb faster at high latitudes (nearer the poles) than at low latitudes (nearer the equator), Rind says. Because latitudinal temperature gradients drive the circulation of air masses around the globe, diminishing the gradient can be expected to reduce the energy driving weather systems.

His model indicates a carbon dioxide doubling would in general slow surface winds, reduce winter and spring storms outside the tropics, reduce the intensity of storms that do occur and slow the eastward transport of pressure systems and air masses across the globe's midlatitudes. A shift to fewer and weaker storms, combined with sluggish movement of air masses, suggests dirty air masses could be left hovering over industrial centers longer than they are today, he says.

Moreover, "with a warmer climate, there's more evaporation of moisture into the air," Rind says. His model predicts that a doubling of carbon dioxide could increase humidity "on the order of 30 to 40 percent." At the same time, there's likely to be more vertical exchange of air — a convective mixing of high- and low-altitude air masses. "Our model also seems to imply that there will be a greater transport of ozone from the stratosphere [upper atmosphere] into the troposphere [lower atmosphere extending down to land]." The obvious implication, Rind says, is that urban smog-ozone levels may be enhanced by ozone generated in the stratosphere.

Greenhouse changes will also affect the chemistry of pollutants in the air at Earth's surface. An urban-smog model being developed at Systems Applications Inc. in San Rafael, Calif., indicates "air will become more reactive in the future," reports C. Shepherd Burton, the company's senior vice president. In a warmer environment, reactions between sunlight