Flying Through the Cosmos

The earth's relation to the universe as a whole exhibits an echo of Galileo's 'Nevertheless it moves'

BY DIETRICK E. THOMSEN

It is now more than a decade since two groups of radio astronomers discovered the background of microwave radiation that pervades the universe. The datum is so simple that it was at first taken for excess antenna noise, and was so announced in what deserves to be regarded as one of the most famous throwaway lines in the history of scientific publication. The possible cosmological implications were buried deep in an inner paragraph due to the trepidation of the observers.

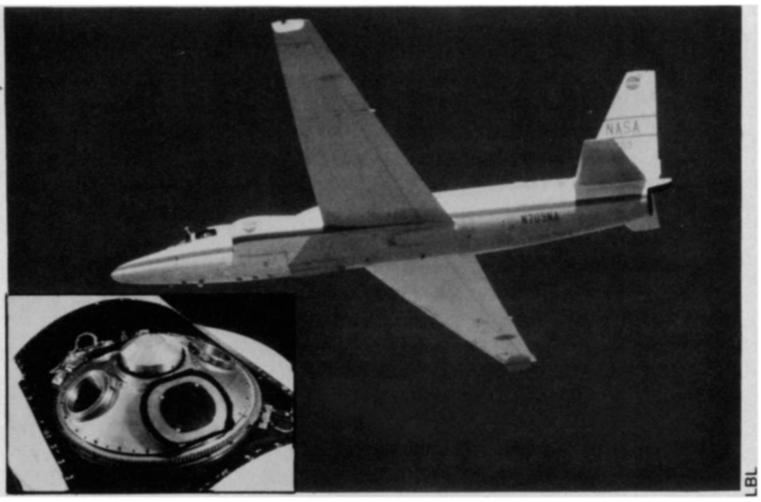
In fact, the first working hypothesis was excess heat contributed by pigeon droppings in the antenna horn. It was only after rigorous checking of the equipment that the observers were willing to adopt the explanation of an excess temperature in the universe—blackbody radiation—what has become known as the three-degree background. (The actual spectrum seems to be working out to 2.7-something degrees K, but the round number is still used as a convenient handle.)

From the suspected relic of a Princeton pigeon to a relic of the creation of the universe is a vast promotion, but it was well equaled by the vast enthusiasm with which cosmologists took up the discovery as a support for the big-bang theory of the universe's origin. At that time the big-bang theory had been lying more or less dormant for about 20 years. It was one of a number of plausible cosmological speculations. By now it has become cosmological orthodoxy, and those who cling to other theories tend to be considered a bit eccentric.

Yet, ten years after the first discovery, observers continue to work on the background radiation, seeking to fill in the points and determine the shape of the spectrum ever more precisely. Why continue this when "everybody" is already convinced, asks P. J. E. Peebles of Princeton University, a theorist who was in on the business at the beginning and has been with it ever since. Because Peebles was making a speech at a meeting of the American Physical Society in Washington, he proceeded to answer his own question: Because of the important things we can learn about the universe from a close study of the background radiation. It is a phenomenon so simple that we can easily interpret it, yet so fundamental that it gives us a deep probe into the nature of the universe.

One of the startling things that has been learned from it most recently is that the earth has a net motion with respect to the background, a kind of 20th century equivalent of the ether drift. The experiment is being done by George Smoot, M. V. Gorenstein and Richard A. Muller of the Lawrence Berkeley Laboratory. Smoot described the experiment at the American Physical Society Meeting and Gorenstein presented the first results at the recent meeting of the American Astronomical Society in Atlanta.

The last time we heard ether drift as the title of an experiment was the famous experiment of Michelson and Morley in the 1880s. The ether then, or more precisely "luminiferous ether," was the substance hypothesized as the carrier of light waves. In 1876 James Clerk Maxwell had published his theory of electricity and magnetism, which predicted the existence of electromagnetic waves and identified light as one manifestation of them. The physicists of the day could not imagine waves without something to be waving. There had to be a physical medium in which the electromagnetic waves would propagate. So the luminiferous ether was invented. Because of the manifest behavior of light, the ether had to be the most superfluid superfluid, pervading all space, even the space inside atoms. Also, because Maxwell's theory showed that electromagnetic waves vibrate transversely to their direction of propagation, the ether had to be able to sustain transverse waves, which meant it had to have highly self-contradictory mechanical properties.



The antennas that measure the temperature of the universal blackbody radiation are carried 20 kilometers above California by a U-2 plame.

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The ether was postulated to be at rest with regard to the universe as a whole. Michelson and Morley determined to measure the earth's motion with regard to the ether by measuring the velocity of light first in the direction of the earth's known motion (that is, east and west) and then at right angles to it. They expected to find a difference in the velocities of light that would enable them to deduce the earth's motion through the ether. They were stunned to find no difference.

The result killed the ether as a physical substance, and led to Einstein's principle of special relativity by which all inertial frames of reference—all frames moving at constant speeds—are equivalent. There is no absolute standard of rest, and the speed of light is constant and the same in all inertial frames. The consequences of special relativity are many and varied, and they permeate the entire structure of modern physics.

The point of all this is that the existence of the microwave background puts us, in a certain sense, back in the 1880s. Not that anyone nowadays proposes a physical ether, but the background radiation, which has been reflected back and forth across the universe for eons, could be a modern version of the ether. It could determine a frame of reference at rest with the universe as a whole.

If we are moving with reference to the microwave background, then if we happen to look forward in the direction of the motion, we should see the background as slightly redshifted. Simultaneous backward observation should show a slight blueshift. The observation is far from easy. Any such motion has to be extremely small (something like one part in a thousand or one in ten thousand) because there has already been a lot of looking in all directions that has found nothing much notable. And there are motions due to local conditions that should show up: The sun rotates around the galaxy; gravity should make our galaxy move toward the Andromeda galaxy, our nearest sizable neighbor, and gravity should also make our whole cluster of galaxies move toward the cluster in the constellation Virgo.

The experiment uses a pair of horn antennas mounted in a U-2 Sky Survey jet that belongs to NASA and flies from Moffett Field, Calif. The flights are made at 20 kilometers altitude and involve reversals of direction to interchange the two antennas (which are pointed 60° apart) and cancel out effects of the equipment. Other precautions are taken to cancel geomagnetic effects and the possible contribution of nonthermal radiation at the experiment's frequency, 33 gigahertz.

What the antennas measure, then, is the effective temperature of the blackbody spectrum. The results of eight flights involving 28 hours of data taking indicate an anisotropy equivalent to a difference of 0.005° K in the 2.7°. This translates to a motion of the earth towards a point in the sky located at about 11 hours right ascension and +6° declination at a rate of 390 ± 60 kilometers per second, or a motion of the Milky Way galaxy in the same direction of 607 ± 70 kilometers per second. Aside from this datum, the temperature of the universal blackbody is isotropic to one part in 3,300, which can be translated to say that if the universe rotates, its rotation rate has to be less than one hundred-billionth (10^{-11}) of a second of arc per century.

Hale Observatories

Our galaxy appears to be moving with respect to the cosmos although it wasn't expected to. Do inhabitants of others find similar results?

Smoot, Gorenstein and Muller are not taking refuge in throwaway lines. A paper they have submitted to PHYSICAL REVIEW LETTERS is plainly entitled "Detection of Anisotropy in the Cosmic Blackbody Radiation," and in it they claim support for their finding in the preliminary results of a different experiment by B. E. Corey and D. T. Wilkinson of Princeton University. At the Astronomical Society meeting the presentation was something of a stunner. One member of the audience tried to express the significance by saying: "If we take this result and the result of [Kent] Ford and [Vera] Rubin [who found an anisotropy in the distribution over the sky of redshifts of distant galaxies], it means that our cluster [of galaxies] and possibly our whole supercluster is moving with respect to the universe." Exactly what that conclusion will mean to cosmology and theoretical physics remains to be seen.

Meanwhile, back at the ranch, other studies of the cosmic blackbody are adding, or can add, further grist to the mills of the gods that grind cosmology. Two of the important characteristics assumed by cosmologists are homogeneity and isotropy. If we start these assumptions and trace the universe backwards, let us see if we come to any contradictions. The first point is that the expansion of the universe was adiabatic. We deal here with the most common cosmological assumption that the universe is a closed system, and there is no other realm into which matter or energy can escape. In particular, no photons, no quanta of electromagnetic energy, get lost from the universe.

This assumption makes the universe a closed box with regard to electromagnetic waves, and that means that as it expands, the blackbody radiation that pervades it simply cools. Or, if we compress it back, the temperature will rise.

Eventually, says Peebles, we arrive at a time, arbitrarily close to the big bang, where this simple assumption that the number of photons is conserved fails. The universe does not lose photons at this point; it gains them.

The test of this proposition is the blackbody nature of the background spectrum itself, that the universe at that point generated blackbody radiation and not something else.

Much of the current observing work has to do with the shortwave end of the spectrum. It is the shortwave end that really proves the case for a blackbody by making an easily recognizable downward curve. The rising part of the spectrum in the longer wavelengths can be part of a non-blackbody spectrum. It is on the downward curve that careful measurements must be made to convince the remaining skeptics that the background really is a blackbody. It is also here, Peebles says, that we can learn something about the "energy budget" of the universe—how much energy was released in the primeval manufacture of heavy elements. At the moment observers do not have definite measurements of the flux in this wavelength region, only upper limits below which it must lie.

Returning to the general questions of the large scale homogeneity and isotropy of the universe, Peebles finds that years of testing the background flux in all directions confirm the two propositions quite well. Of course there must be small scale inhomogeneities: Matter and energy are not spread out with the smoothness of cake batter. Electrons, pebbles, planets and stars all exist, and each of these is an example of inhomogeneity on a different (but still small) scale.

Peebles then mentions two "wild-eyed speculations" about what the background radiation may be able to teach us. The first concerns the so-called primeval black holes.

Stephen Hawking of Cambridge University, one of the prominent cosmological theorists, has proposed that the big bang made a large number of miniature black holes. Unlike the black holes that result from the deaths of stars, these would have very small masses and almost microscopic dimensions. They should be peppered all over the universe. Since black holes absorb radiation that strike them, they should appear as tiny black spots against the background. Peebles suggests that the Very Large Array radiotelescope now being built in New Mexico may have a resolving power capable of finding such primeval black holes if they exist.

The second wild speculation concerns the origins of galaxies, one of the most difficult cosmological questions and one in which Peebles has been interested for a long time. Peebles refers us to the epoch represented by a redshift of 1,000. Cosmologists often use redshift as a shorthand for time, because in the general modern view the redshift of the light of a distant object determines its distance in space, and its distance in space necessarily determines how long ago the light we now see left the object. So redshift can be used as a shorthand for time scale.

The epoch of redshift 1,000 should be a time when galaxies were just forming. They would have been big and mostly gas, not yet articulated into stars. They would have plated the sky, and the blackbody radiation going through them would have suffered kicks. By studying the blackbody radiation now, we may be able to determine the masses and abundance of such infant galaxies. ☐