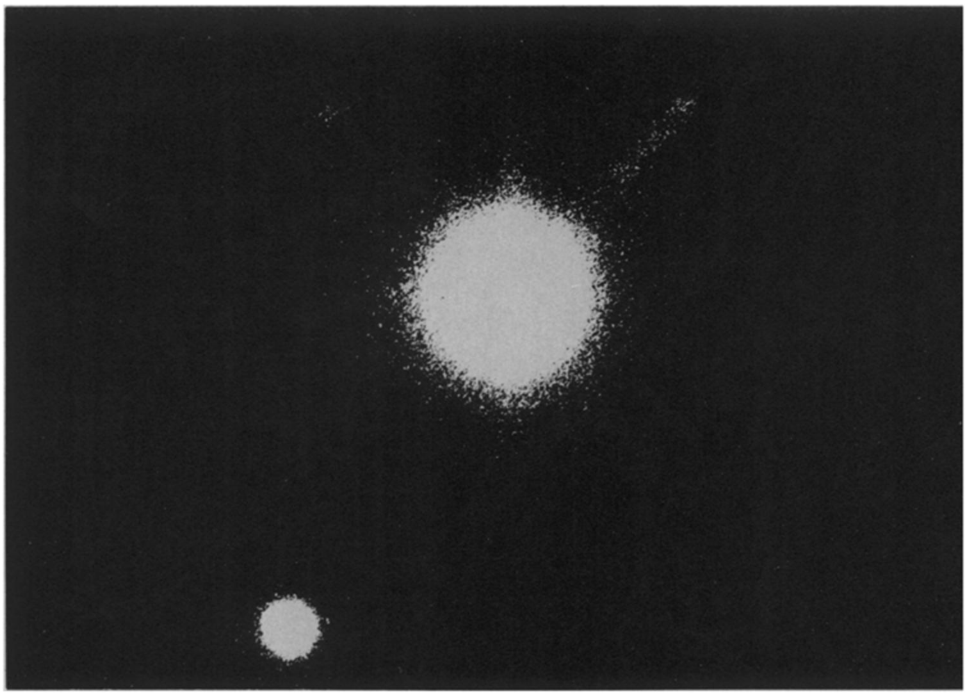
Cosmic Archaeology

Its Lake Rudolph is a sea of microwaves, but the attempt to delineate the shape of the cosmic past has its bones of contention, too

BY DIETRICK E. THOMSEN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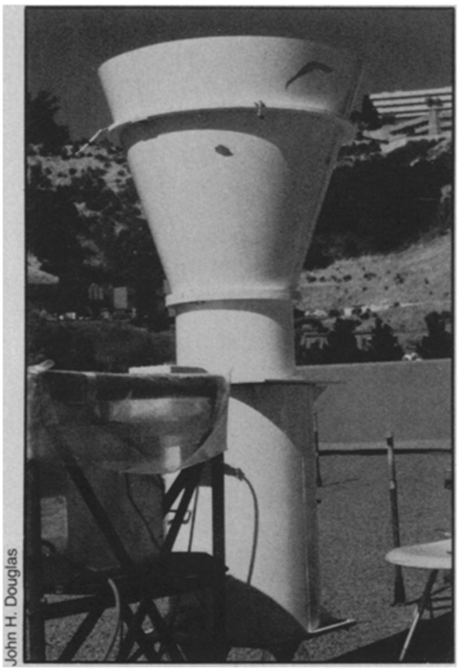
3C273 is a famous example of the things that are controversial about quasars.

Edwin Hubble and his contemporaries began the study of modern cosmology with systematic investigations of the galaxies, which only through their work came to be recognized as giant systems of stars independent of and extremely distant from the system in which we find ourselves. Since then, cosmologists have penetrated backward and downward layer by layer into the history of the universe into regions that are far less familiar to our sight and much more disturbing to our philosophy. No Virgil has yet shown up to guide us, but one piece of Virgil's advice, appropriate as it may seem to some people at some times, has definitely not been taken: *Non ragionam di lor, ma guarda e passa.* (Let's not discuss them, just look and pass on.) Scientists talking up Hubble's determination that the universe is expanding came up with the big bang theory, which turned inferno into an act of creation.

In the beginning, according to the big bang theory, the universe was all radiation, that is, light. Radiation begat matter, and, gradually from a human sense of time, very quickly from a cosmological point of view, matter came to dominate. As this process was going on, the universe was expanding. The time came when there was enough room for some of this light to decouple from the matter. That is, the light was able to keep running through the universe without encountering matter that would absorb and reradiate it. The light kept running for 19,999,500,000 years or so until now some of it gets absorbed in the receivers of our radio telescopes.

What was then ultrahigh energy gamma rays appears now as rather low energy radio waves in the millimeter range. The shape of its spectrum is that of a blackbody or perfect thermal radiator at a temperature about 2.7°K. This, too, is quite a change from the millions of degrees that prevailed at the decoupling time, but the theory provides naturally for both of them. They can be viewed as a redshift caused by the expansion of the universe, just as the light that started out somewhat later from galaxies and quasars is redshifted, or they can be seen as adiabatic cooling caused by the expansion of the universe. The explanations support each other.


John H. Douglas

Blackbody polarization observation.

If one accepts the big bang theory's interpretation of these data—and only a few cosmologists object strenuously—then it is clear that the background radiation is a cosmological fossil of extreme importance. Undisturbed since the year 500,000 p.c. (*post creationem* or after the big bang) it carries information about conditions before that time. Study of its details may be able to extract the information.

Studies are proceeding from the grosser aspects of the background radiation to more and more subtle ones—it is interesting to see just what subtle effects astrophysicists believe they may someday be able to measure — and they have already dropped one brick in the smooth, still pond of theoretical contemplation. George Smoot of the Lawrence Berkeley Laboratory and collaborators reported (SN: 7/16/77, p. 44) that there is an anisotropy in the background radiation. What we receive depends to a slight degree on the direction we look.

Along a particular axis, which runs toward the Virgo cluster of galaxies, the radiation seems to be three millidegrees cooler in one direction, three millidegrees warmer in the other. This datum can be interpreted as a motion of our galactic cluster toward the Virgo cluster, a motion superimposed on the general expansion of the universe.

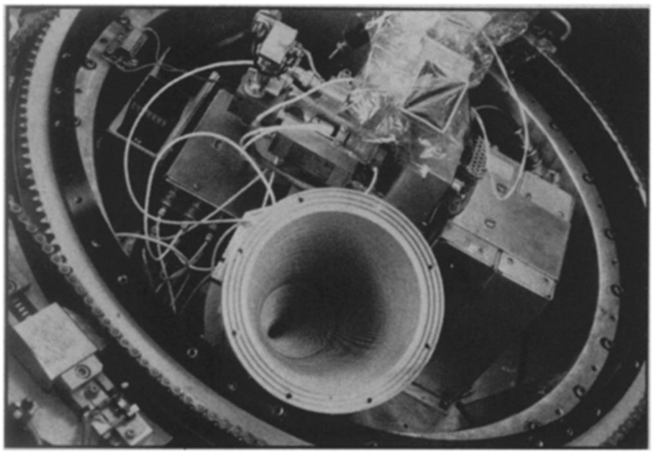
Such a differential motion can have some very cosmic consequences. It can be argued that the blackbody background represents a frame of reference that is at rest with respect to the universe. It has something of the quality of the "luminiferous aether" of nineteenth century theory. The status of the blackbody radiation as a universal rest standard is useful only if something moves against it. If the denser parts of the universe, all the clusters of galaxies, are participating evenly in the universal expansion, they will all be at rest with respect to the blackbody background, and its position as absolute rest will be nugatory.

Belief in the luminiferous aether died away after the experiment of Michelson and Morley simply because they had failed to detect any motion of anything against the aether, by which the existence of the aether could be known. The experiment of Smoot and collaborators has found an apparent motion. On further interpretation it may make trouble for the basic notion of modern physics that there are no priviledged points in space and no frame of reference is any more at rest than any other — if not in the abstract reaches of philosophy at least in the one and only universe that we know about. A perhaps more radical possible interpretation is that the universal expansion is not smooth but lopsided. For this, says Smoot, nobody has any models. Cosmological models have traditionally been built on the assumption that space expands evenly.

So the finding definitely bears checking. The original observations were made from a U-2 airplane flying over northern California. Now negotiations are underway with NASA, the owner of the plane, to take it to South America for some flights. A universal effect should look the same in the southern hemisphere as in the northern, but the southern sky has surprised astronomers before now, says Smoot. Observers expected galaxy counts to be the same, but it turned out that the presence of some large nearby galaxy clusters in the north makes a significant difference.

Meanwhile, a more sophisticated version of the experiment is being planned for the Cosmic Background Explorer Satellite, which is due to be launched in about four years. In this endeavor Smoot is associated with Rainer Weiss of Massachusetts Institute of Technology, David T. Wilkinson of Princeton University (one of the discoverers of the blackbody radiation), Michael Hauser and John Mather of the Goddard Space Flight Center, and Samuel Gulkis of the Jet Propulsion Laboratory. One of the things the CBES will do is look for the anisotropy effect at four frequencies instead of the one investigated so far. The idea is that if the effect does not appear at other points in the spectrum or if it appears with a variable relation to frequency, the explanation will become several degrees more complicated.

Baldwin



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Horn antenna measured blackbody background from the top of U2.

Lick/Univ. of Calif.

Wampler

Caltech

Schmidt

John H. Douglas

Smoot

There are other characteristics of the blackbody that can also be studied. An experiment by Smoot, Phillip Lubin and Phillip Dauber to study the polarization of the radiation has just begun to operate on the roof of the building in Berkeley where their offices are. It is a slow experiment — it takes a long time to integrate the data — but it has the advantage that it can be done on the rooftop or, if that proves too noisy, from a mountaintop. If the universe is homogeneous and isotropic, the radiation should be completely unpolarized. If the universe expands anisotropically, the radiation will be polarized. This observation can be a more precise check on the studies of the temperature or amplitude of the radiation. So far about two months' data have been taken, so it is far too early to know anything.

In the blue sky category, in more ways than one, is an idea of Smoot and Weiss to do a photon counting experiment on the blackbody. A true blackbody should have certain photon statistics, a certain pattern of arrival of the photons of energy that make up the radiation. Inhomogeneities in the universe at the decoupling time could alter that pattern. The point is, as Smoot emphasizes, that at some time inhomogeneities have to appear. The genesis of galaxies or clusters of galaxies is one of the most difficult questions in every cosmological model. If the clumping they represent had started before the decoupling time, then it may show up in the photon pattern of the blackbody radiation. It may be possible to set up a photon counting apparatus that could record such patterns.

The next archaeological stratum, so to speak, is light from the first stars that ever formed and are now long vanished. This light decoupled from matter rather later than the microwave background, and so has not been redshifted nearly so much. The microwave background spectrum peaks at about one centimeter wavelength; this primordial starlight peaks in the infrared, in the hundreds of microns. The Cosmic Background Explorer Satellite will look for it. The major difficulty is seeing it against the interference of the zodiacal light, scattered starlight from within our own galaxy.

If it proves recordable, the primordial starlight could give us information about the early chemistry of the universe and the subsequent development of stellar evolution — for example, how much hydrogen and helium could have been turned into heavier elements, how many black holes there may be around that once were stars and burned out or how many planets there could be.

Astronomers don't have to determine whether we can see the light emitted from quasars, which may be the next, or a coeval, historical development. The quasar light is visible; the arguments are over what it means. One of the furious ones concerns the relevance of quasars to cosmology. Are they largely relics of the universal past?

The redshifts that appear in the quasars' light, if taken as cosmological, would indicate that most of the quasars belong to the distant past, but some astrophysicists have serious difficulties accepting this — large distance requires weird astrophysics for the quasars' energy production among other things — and controversy continues to simmer. At first the dissentients proposed that the large redshifts were due to gravity, that strong gravitational fields in the quasars reddened their light. That ar-

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ticular kind of infrared stars that have shells around them, and about planetary nebulae.

This is truly the borderland between radio and infrared, and in fact, Leighton says, the working telescope is instrumented by groups interested in broadband measurements, who use bolometers, essentially an infrared recording technique, and those wanting to chart particular spectral lines, who use radio receivers.

The interferometric detail is of interest not only to the stellar astronomers and cosmologists studying the interstellar clouds, but also to those whose territory is closer to home. The planets do enjoy a similar chemical and temperature regime to that of the interstellar clouds, and much of their emanations come in the millimeter wave range. This instrument could resolve such details as the satellites of Jupiter and Saturn and some of the asteroids. Planetary astronomers from the Jet Propulsion Laboratory, where a lot of NASA's planetary work has been located, are interested.

There is also a remote possibility of some interferometry at Mauna Kea, where the telescope will suffer less from atmospheric absorption of the incoming radiation than at Owens Valley (Mauna Kea being a much higher elevation). The National Radio Astronomy Observatory has wanted to build a 25-meter radio telescope on Mauna Kea, and if it ever does that telescope could serve as a fixed-baseline interferometer with the 10-meter one that Caltech will have there.

Caltech

Honeycomb material is ground to mirror surface then coated with aluminum.

And ultimately there is the not-impossible question of very long baseline interferometry (VLBI). VLBI is a technique much used at longer radio wavelengths in which observations made of the same object at the same time by widely separated telescopes are recorded on tape and combined in a computer and thereby simulate an interferometer as big as the space between the telescopes. With this technique radio astronomers have simulated the resolution of a telescope as wide as the earth. Leighton says he was talking about this project to Marshall Cohen, one of the prominent practitioners of VLBI. "I said: 'Someday you're going to want to use the millimeter waves for VLBI'; and he said: 'Don't think we aren't thinking of it.'" ☐

gument has largely disappeared, and the redshifts are now referred to some phenomenon of nature yet unknown.

However, there is an interesting relation between the numbers of observed quasars and their redshifts: the higher the redshift, the more quasars. If one takes the redshifts to be representative of distance in time and space, this means the quasars belong mostly to the distant past. That is what is done by Maarten Schmidt, the recently appointed director of the Hale Observatories. Schmidt does volume counts of quasars, seeking to determine the space densities of quasars in different past epochs. His work takes account of the expansion of the universe, but finds nevertheless that quasars were much more thickly packed in space in long past epochs than they are now. At very large distances, he says, say four-fifths of the age of the universe (16 billion years ago), the space density goes up by a thousand.

Schmidt concludes that quasars are therefore a phenomenon of the early universe. It was somehow easier for them to form in early times when matter and energy were more closely packed. Gradually most of them evolved to something else or burned out. There's no law against a quasar forming now, but it's unlikely. "Suddenly you realize that we seem to be living at the end of the fireworks," he says. "The show is just about over."

But as the captains and the kings depart, they need a candle to light their way offstage. As the cosmologists contemplate the end of the show they want a standard candle, a way of making sure, among other things, that the redshift-distance relation is exact enough to be a measure of what the expansion of the universe has done and is doing and will do.

The question of the quasar redshifts could be solved by finding an independent way of determining quasar distances. This is where the standard candle comes in. A light made to have a known intrinsic luminosity can be used to measure distances. The farther away it is, the dimmer it will look. Comparing its apparent luminosity at any location with its standard intrinsic luminosity will yield the distance.

Are there any quasars that can serve as standard candles? Not quite. But recent work reported from the Lick Observatory (in the June 8 NATURE) promises to provide almost exactly this means. It will enable astronomers to use a measurable physical characteristic of a quasar to determine that quasar's intrinsic luminosity, which amounts to the same thing as having a standard candle out there.

Jack A. Baldwin of the Institute of Astronomy in Cambridge, England, postulated that the intrinsic brightness of a quasar should be related to the width of a particular line in the quasar's spectrum. (The line width depends on the amount of motion of atoms in the object, and that should be related to the amount of energy being generated.) Baldwin tried this idea on a selection of quasar spectra, but with less than convincing results.

"Jack's data were taken from an inhomogeneous sample," says Joseph Wampler of Lick, one of those who collaborated on the later effort. It was a group of quasars chosen for another purpose plus some others added on. It was open to the objection that it favored optically faint quasars, in whose spectra the lines show up stronger than they do in the spectra of bright ones, and that it included quasars of widely varying redshift, which meant that assumptions about the meaning of the redshift had to be added in.

Baldwin, William L. Burke, C. Martin Gaskell and Wampler proceeded to take a group of quasars that would be free of these objections. The quasars were selected on radio criteria (a flat radio spectrum) so that characteristics of their optical spectra would not influence the selection. They were all between redshift 1.1 and 1.4 so that cosmological models based on redshift would not matter. "The hypothesis was confirmed beautifully," Wampler says.

The group thought so well of the result that they made a Hubble diagram, a graph of velocity versus distance, from which one should be able to determine the curvature of the universe and conclude that someday the universe will stop expanding and begin to collapse. This answer to one of cosmology's fundamental questions is the diametrical opposite to the conclusion in favor of a universe that is not only expanding forever, but expanding with an acceleration, repeated a few weeks before by Beatrice Tinsley of Yale University (See p. 141). Wampler remarks that to reach that conclusion she puts in evolutionary effects, the proposition that the objects studied change with time and therefore are not physically the same at all redshifts. Somehow the disparate conclusions will someday have to be reconciled.

Somehow a lot of other disparities will have to be resolved. We can return to the galaxies where Hubble and his contemporaries began. It is difficult to make a galaxy into a standard candle. They are too various physically, and too many factors affect their luminosity. But just by taking a lot of factors and defining a class of galaxies very narrowly, it may be possible to get them to have the same or nearly the same intrinsic brightness. This was tried by Vera Rubin of the Carnegie Institution of Washington and Kent Ford of Kitt Peak National Observatory. They studied the distribution of redshifts of a narrow class of galaxies (ScI) over the southern sky and found an anisotropy that could be interpreted as a velocity of our cluster toward a point in the sky (SN: 8/18/73, p. 114). But it's a different velocity and a different point from those indicated by the studies of the blackbody radiation. That's another thing that will have to be reconciled, Smoot says. ☐