of the first four interlopers, provided the initial clue to the existence of radio-quiet, blue, quasi-stellar galaxies (QSG) whose optical properties are similar to those of QSS's (Sandage 1965).

Spectrograms were subsequently obtained for BSO 1, BSO 8, and BSO 16 by Schmidt and by Sandage in an attempt to verify the existence of QSG. The spectrum of BSO 16 shows that this object is a hot star having the Balmer lines in absorption near their rest wavelengths. This was expected on the basis of the non-peculiar $U - B$, $B - V$ colors. The spectrum of BSO 8 (called "BSO 105" by Sandage 1965 on an older numbering system) is continuous with no prominent absorption or emission lines. BSO 1 has a large redshift of $\Delta\lambda/\lambda_0 = 1.2410$, as described elsewhere (Sandage 1965).

Table 1 lists the precise optical positions of the first four interlopers, and estimated positions, accurate to perhaps $\pm 20''$, for the thirty-one survey objects. Where available, the colors and magnitudes determined photoelectrically at the 200-inch are also shown.

These blue objects are undoubtedly of the same class as the faint objects in the catalogues of Iriarte and Chavira (1957), Chavira (1958), and Haro and Luyten (1962). With the identification of most of these objects as intrinsically bright stellar-appearing galaxies, these catalogues provide a large finding list that can be surveyed by radio techniques to determine if the QSG's are weak radio emitters. It is expected that such study will shed light on the evolutionary process of radio decay after the intense QSS radio phase.

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COSMIC BLACK-BODY RADIATION*

One of the basic problems of cosmology is the singularity characteristic of the familiar cosmological solutions of Einstein's field equations. Also puzzling is the presence of matter in excess over antimatter in the universe, for baryons and leptons are thought to be conserved. Thus, in the framework of conventional theory we cannot understand the origin of matter or of the universe. We can distinguish three main attempts to deal with these problems.

1. The assumption of continuous creation (Bondi and Gold 1948; Hoyle 1948), which avoids the singularity by postulating a universe expanding for all time and a continuous but slow creation of new matter in the universe.

2. The assumption (Wheeler 1964) that the creation of new matter is intimately related to the existence of the singularity, and that the resolution of both paradoxes may be found in a proper quantum mechanical treatment of Einstein's field equations.

3. The assumption that the singularity results from a mathematical over-idealization,

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the requirement of strict isotropy or uniformity, and that it would not occur in the real world (Wheeler 1958; Lifshitz and Khalatnikov 1963).

If this third premise is accepted tentatively as a working hypothesis, it carries with it a possible resolution of the second paradox, for the matter we see about us now may represent the same baryon content of the previous expansion of a closed universe, oscillating for all time. This relieves us of the necessity of understanding the origin of matter at any finite time in the past. In this picture it is essential to suppose that at the time of maximum collapse the temperature of the universe would exceed 10^{10} ° K, in order that the ashes of the previous cycle would have been reprocessed back to the hydrogen required for the stars in the next cycle.

Even without this hypothesis it is of interest to inquire about the temperature of the universe in these earlier times. From this broader viewpoint we need not limit the discussion to closed oscillating models. Even if the universe had a singular origin it might have been extremely hot in the early stages.

Could the universe have been filled with black-body radiation from this possible high-temperature state? If so, it is important to notice that as the universe expands the cosmological redshift would serve to adiabatically cool the radiation, while preserving the thermal character. The radiation temperature would vary inversely as the expansion parameter (radius) of the universe.

The presence of thermal radiation remaining from the fireball is to be expected if we can trace the expansion of the universe back to a time when the temperature was of the order of 10^{10} ° K ($\sim m_e c^2$). In this state, we would expect to find that the electron abundance had increased very substantially, due to thermal electron-pair production, to a density characteristic of the temperature only. One readily verifies that, whatever the previous history of the universe, the photon absorption length would have been short with this high electron density, and the radiation content of the universe would have promptly adjusted to a thermal equilibrium distribution due to pair-creation and annihilation processes. This adjustment requires a time interval short compared with the characteristic expansion time of the universe, whether the cosmology is general relativity or the more rapidly evolving Brans-Dicke theory (Brans and Dicke 1961).

The above equilibrium argument may be applied also to the neutrino abundance. In the epoch where $T > 10^{10}$ ° K, the very high thermal electron and photon abundance would be sufficient to assure an equilibrium thermal abundance of electron-type neutrinos, assuming the presence of neutrino-antineutrino pair-production processes. This means that a strictly thermal neutrino and antineutrino distribution, in thermal equilibrium with the radiation, would have issued from the highly contracted phase. Conceivably, even gravitational radiation could be in thermal equilibrium.

Without some knowledge of the density of matter in the primordial fireball we cannot predict the present radiation temperature. However, a rough upper limit is provided by the observation that black-body radiation at a temperature of 40° K provides an energy density of 2×10^{-29} gm cm^3, very roughly the maximum total energy density compatible with the observed Hubble constant and acceleration parameter. Evidently, it would be of considerable interest to attempt to detect this primeval thermal radiation directly.

Two of us (P. G. R. and D. T. W.) have constructed a radiometer and receiving horn capable of an absolute measure of thermal radiation at a wavelength of 3 cm. The choice of wavelength was dictated by two considerations, that at much shorter wavelengths atmospheric absorption would be troublesome, while at longer wavelengths galactic and extragalactic emission would be appreciable. Extrapolating from the observed background radiation at longer wavelengths ($\sim$ 100 cm) according to the power-law spectra characteristic of synchrotron radiation or bremsstrahlung, we can conclude that the total background at 3 cm due to the Galaxy and the extragalactic sources should not exceed 5×10^{-3} ° K when averaged over all directions. Radiation from stars at 3 cm is

$< 10^{-9}$ ° K. The contribution to the background due to the atmosphere is expected to be approximately 3.5° K, and this can be accurately measured by tipping the antenna (Dicke, Beringer, Kyhl, and Vane 1946).

While we have not yet obtained results with our instrument, we recently learned that Penzias and Wilson (1965) of the Bell Telephone Laboratories have observed background radiation at 7.3-cm wavelength. In attempting to eliminate (or account for) every contribution to the noise seen at the output of their receiver, they ended with a residual of 3.5° ± 1° K. Apparently this could only be due to radiation of unknown origin entering the antenna.

It is evident that more measurements are needed to determine a spectrum, and we expect to continue our work at 3 cm. We also expect to go to a wavelength of 1 cm. We understand that measurements at wavelengths greater than 7 cm may be filled in by Penzias and Wilson.

A temperature in excess of 10^{10} ° K during the highly contracted phase of the universe is strongly implied by a present temperature of 3.5° K for black-body radiation. There are two reasonable cases to consider. Assuming a singularity-free oscillating cosmology, we believe that the temperature must have been high enough to decompose the heavy elements from the previous cycle, for there is no observational evidence for significant amounts of heavy elements in outer parts of the oldest stars in our Galaxy. If the cosmological solution has a singularity, the temperature would rise much higher than 10^{10} ° K in approaching the singularity (see, e.g., Fig. 1).

It has been pointed out by one of us (P. J. E. P.) that the observation of a temperature as low as 3.5° K, together with the estimated abundance of helium in the protogalaxy, provides some important evidence on possible cosmologies (Peebles 1965). This comes about in the following way. Considering again the epoch $T \gg 10^{10}$ ° K, we see that the presence of the thermal electrons and neutrinos would have assured nearly equal abundances of neutrons and protons. Once the temperature has fallen so low that photodissociation of deuterium is not too great, the neutrons and protons can combine to form deuterium, which in turn readily burns to helium. This was the type of process envisioned by Gamow, Alpher, Herman, and others (Alpher, Bethe, and Gamow 1948; Alpher, Follin, and Herman 1953; Hoyle and Tayler 1964). Evidently the amount of helium produced depends on the density of matter at the time helium formation became possible. If at this time the nucleon density were great enough, an appreciable amount of helium would have been produced before the density fell too low for reactions to occur. Thus, from an upper limit on the possible helium abundance in the protogalaxy we can place an upper limit on the matter density at the time of helium formation (which occurs at a fairly definite temperature, almost independent of density) and hence, given the density of matter in the present universe, we have a lower limit on the present radiation temperature. This limit varies as the cube root of the assumed present mean density of matter.

While little is reliably known about the possible helium content of the protogalaxy, a reasonable upper bound consistent with present abundance observations is 25 per cent helium by mass. With this limit, and assuming that general relativity is valid, then if the present radiation temperature were 3.5° K, we conclude that the matter density in the universe could not exceed 3×10^{-32} gm cm^3. (See Peebles 1965 for a detailed development of the factors determining this value.) This is a factor of 20 below the estimated average density from matter in galaxies (Oort 1958), but the estimate probably is not reliable enough to rule out this low density.

CONCLUSIONS

While all the data are not yet in hand we propose to present here the possible conclusions to be drawn if we tentatively assume that the measurements of Penzias and Wilson (1965) do indicate black-body radiation at 3.5° K. We also assume that the universe can be considered to be isotropic and uniform, and that the present energy density in gravi-

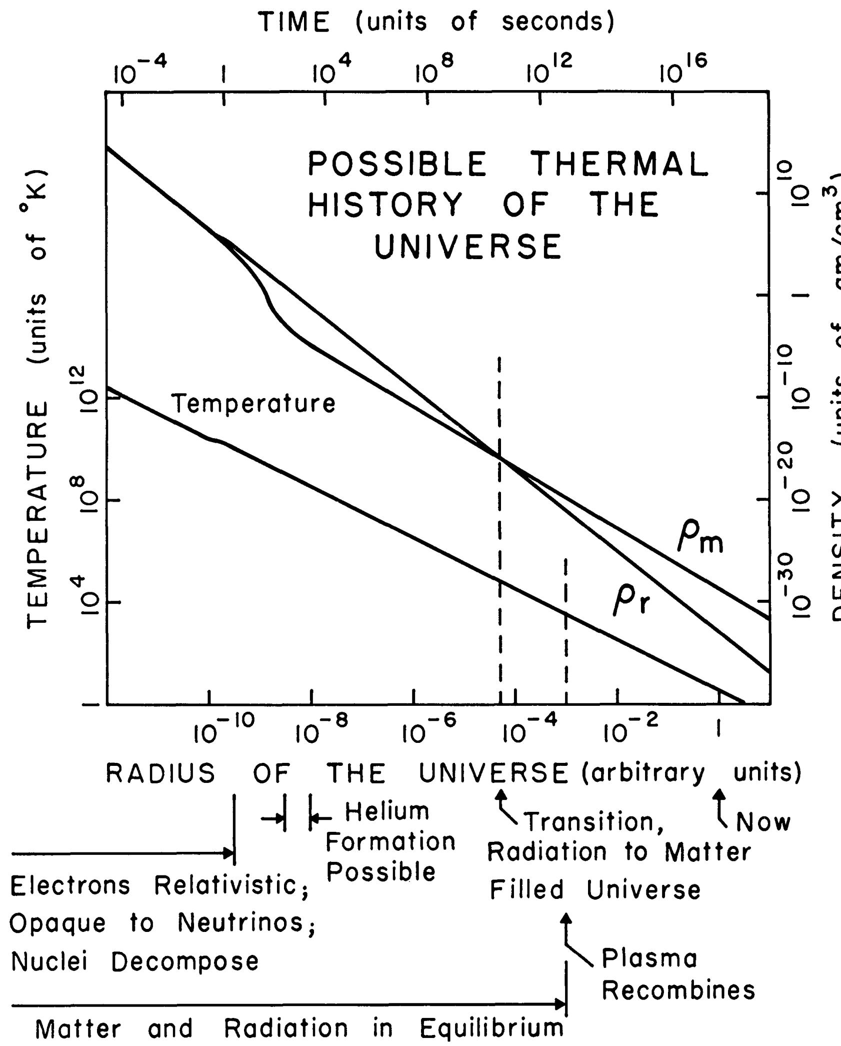

FIG 1 —Possible thermal history of the Universe. The figure shows the previous thermal history of the Universe assuming a homogeneous isotropic general-relativity cosmological model (no scalar field) with present matter density 2×10^{-29} gm/cm^3 and present thermal radiation temperature 3.5° K The bottom horizontal scale may be considered simply the proper distance between two chosen fiducial co-moving galaxies (*points*) The top horizontal scale is the proper world time. The line marked "temperature" refers to the temperature of the thermal radiation Matter remains in thermal equilibrium with the radiation until the plasma recombines, at the time indicated Thereafter further expansion cools matter not gravitationally bound faster than the radiation. The mass density in radiation is ρ_r. At present ρ_r is substantially below the mass density in matter, ρ_m, but, in the early Universe ρ_r exceeded ρ_m We have indicated the time when the Universe exhibited a transition from the characteristics of a radiation-filled model to those of a matter-filled model.

Looking back in time, as the temperature approaches 10^{10} ° K the electrons become relativistic, and thermal electron-pair creation sharply increases the matter density At temperatures somewhat greater than 10^{10} ° K these electrons should be so abundant as to assure a thermal neutrino abundance and a thermal neutron-proton abundance ratio. A temperature of this order would be required also to decompose the nuclei from the previous cycle in an oscillating Universe. Notice that the nucleons are non-relativistic here.

The thermal neutrons decay at the right-hand limit of the indicated region of helium formation. There is a left-hand limit on this region because at higher temperatures photodissociation removes the deuterium necessary to form helium The difficulty with this model is that most of the matter would end up in helium.

tational radiation is a small part of the whole. Wheeler (1958) has remarked that gravitational radiation could be important.

For the purpose of obtaining definite numerical results we take the present Hubble redshift age to be 10^{10} years.

Assuming the validity of Einstein's field equations, the above discussion and numerical values impose severe restrictions on the cosmological problem. The possible conclusions are conveniently discussed under two headings, the assumption of a universe with either an open or a closed space.

Open universe.—From the present observations we cannot exclude the possibility that the total density of matter in the universe is substantially below the minimum value 2×10^{-29} gm cm^3 required for a closed universe. Assuming general relativity is valid, we have concluded from the discussion of the connection between helium production and the present radiation temperature that the present density of material in the universe must be $\lesssim 3 \times 10^{-32}$ gm cm^3, a factor of 600 smaller than the limit for a closed universe. The thermal-radiation energy density is even smaller, and from the above arguments we expect the same to be true of neutrinos.

Apparently, with the assumption of general relativity and a primordial temperature consistent with the present 3.5° K, we are forced to adopt an open space, with very low density. This rules out the possibility of an oscillating universe. Furthermore, as Einstein (1950) remarked, this result is distinctly non-Machian, in the sense that, with such a low mass density, we cannot reasonably assume that the local inertial properties of space are determined by the presence of matter, rather than by some absolute property of space.

Closed universe.—This could be the type of oscillating universe visualized in the introductory remarks, or it could be a universe expanding from a singular state. In the framework of the present discussion the required mass density in excess of 2×10^{-29} gm cm^3 could not be due to thermal radiation, or to neutrinos, and it must be presumed that it is due to ordinary matter, perhaps intergalactic gas uniformly distributed or else in large clouds (small protogalaxies) that have not yet generated stars (see Fig. 1).

With this large matter content, the limit placed on the radiation temperature by the low helium content of the solar system is very severe. The present black-body temperature would be expected to exceed 30° K (Peebles 1965). One way that we have found reasonably capable of decreasing this lower bound to 3.5° K is to introduce a zero-mass scalar field into the cosmology. It is convenient to do this without invalidating the Einstein field equation, and the form of the theory for which the scalar interaction appears as an ordinary matter interaction (Dicke 1962) has been employed. The cosmological equation (Brans and Dicke 1961) was originally integrated for a cold universe only, but a recent investigation of the solutions for a hot universe indicates that with the scalar field the universe would have expanded through the temperature range $T \sim 10^9$ ° K so fast that essentially no helium would have been formed. The reason for this is that the static part of the scalar field contributes a pressure just equal to the scalar-field energy density. By contrast, the pressure due to incoherent electromagnetic radiation or to relativistic particles is one third of the energy density. Thus, if we traced back to a highly contracted universe, we would find that the scalar-field energy density exceeded all other contributions, and that this fast increasing scalar-field energy caused the universe to expand through the highly contracted phase much more rapidly than would be the case if the scalar field vanished. The essential element is that the pressure approaches the energy density, rather than one third of the energy density. Any other interaction which would cause this, such as the model given by Zel'dovich (1962), would also prevent appreciable helium production in the highly contracted universe.

Returning to the problem stated in the first paragraph, we conclude that it is possible to save baryon conservation in a reasonable way if the universe is closed and oscillating. To avoid a catastrophic helium production, either the present matter density should be $< 3 \times 10^{-32}$ gm/cm^3, or there should exist some form of energy content with very high pressure, such as the zero-mass scalar, capable of speeding the universe through the period of helium formation. To have a closed space, an energy density of 2×10^{-29} gm/cm^3 is needed. Without a zero-mass scalar, or some other "hard" interaction, the energy could not be in the form of ordinary matter and may be presumed to be gravitational radiation (Wheeler 1958).

One other possibility for closing the universe, with matter providing the energy content of the universe, is the assumption that the universe contains a net electron-type neutrino abundance (in excess of antineutrinos) greatly larger than the nucleon abundance. In this case, if the neutrino abundance were so great that these neutrinos are degenerate, the degeneracy would have forced a negligible equilibrium neutron abundance in the early, highly contracted universe, thus removing the possibility of nuclear reactions leading to helium formation. However, the required ratio of lepton to baryon number must be $> 10^9$.

We deeply appreciate the helpfulness of Drs. Penzias and Wilson of the Bell Telephone Laboratories, Crawford Hill, Holmdel, New Jersey, in discussing with us the result of their measurements and in showing us their receiving system. We are also grateful for several helpful suggestions of Professor J. A. Wheeler.

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A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and