THE COSMIC BACKGROUND RADIATION: SOME RECENT DEVELOPMENTS

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1. Introduction

Diffuse background radiation has been detected over 16 decades of frequency – from a few MHz up to $\sim 3\times 10^{16}$ MHz (100 MeV) – and there are upper limits over an even wider range. Generally an important contribution comes from the galactic disc, but in some wavebands it has proved possible to isolate a truly cosmic isotropic component originating beyond our own Galaxy. A simple Olbers-type argument shows that the bulk of any extragalactic radiation field originates at cosmological distances. This is true whether the radiation is emitted by discrete sources, or comes from extragalactic (or pregalactic) space. Thus studies of the isotropic background radiation, or even upper limits to its intensity, yield data that are vital for cosmology, as well as telling us something about the properties of diffuse intergalactic matter, and about intrinsically faint extragalactic objects which cannot be observed individually.

In this talk I shall not attempt a systematic review of this extensive subject, but will merely discuss a few recent developments. I shall give special attention to the microwave and X-ray regions of the spectrum, as these are the two bands in which the cosmic background is so strong that it swamps the emission from the Galaxy.

2. The Isotropic Microwave Background

At wavelengths $\gtrsim 50$ cm the background radiation appears to be dominated by the contribution from non-thermal synchrotron sources. The strong dependence on galactic latitude indicates that much comes from our own Galaxy. At shorter wavelengths, however, it becomes isotropic, with a spectrum $I(\nu)\propto \nu^2$ (in contrast to the spectrum $\nu^{-0.7}$–$\nu^{-0.9}$ estimated for the extragalactic background at longer wavelengths). This new component, discovered by Penzias and Wilson (1965) at 7 cm, was quickly realised to possess crucial cosmological significance (Dicke *et al.*, 1965). Subsequent ground-based observations at wavelengths ranging from 74 cm to 3.3 mm showed the spectrum to be consistent with that of a 2.7 K black body. This conclusion was further supported by studies of the rotational excitation of interstellar molecules seen in absorption in stellar spectra. Similar excitation conditions are inferred from observations of 11 different stars. This suggests an excitation mechanism which is uniform, at least throughout the solar neighbourhood, and although one cannot completely exclude collisional excitation by ions or electrons, it is generally assumed that background radiation is responsible. These observations yield an estimate of ~ 3 K for the background temperature at 2.62 mm (from CN), together with upper

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limits at 1.31 mm (CN), 0.56 mm (CH) and 0.36 mm (CH^+). These limits lie above a 2.7 K black body, but fall below a grey body extrapolation of the Rayleigh-Jeans segment of the spectrum (Clauser and Thaddeus, 1970).

As is well known, this remarkably intense, and apparently thermal, background is commonly interpreted as the 'relict' radiation from the primordial fireball which was originally hypothesised by Gamow (1949). I shall not discuss these observations in any detail here, nor the astrophysical and cosmological speculations that they have provoked. All these matters have been excellently reviewed by Dautcourt and Wallis (1968), Partridge (1969) and Field (1969a), among others. Instead, I shall describe some more recent experiments which suggest that at millimetre wavelengths the background intensity far exceeds that expected from a 2.7 K black body, and then consider the extent to which the 'conventional wisdom' would have to be reappraised if these tentative observations were correct.

A 2.7 K black body spectrum peaks at around 2 mm wavelength. The band around 1 mm, which is obviously crucially important in settling the true nature of the background, cannot, owing to atmospheric absorption, be studied directly from ground level. Within the last two years, however, direct observations in this waveband have been carried out from above the Earth's atmosphere. These observations have somewhat confused the theoretical picture by revealing an unexpectedly high radiation intensity. If the reported flux pervades the whole Galaxy, rather than being a local phenomenon, its strength is in fact hard to reconcile with the indirect upper limits inferred from the interstellar molecular lines.

In 1968 a joint NRL-Cornell group flew a rocket containing a liquid helium cooled detector sensitive to radiation in the 0.4–1.3 mm band, which was exposed at ~ 100 km altitude. Radiation with an estimated energy density ~ 20 eV cm^{-3} was detected (Shivanandan *et al.*, 1968). Two perpendicular strips of sky were scanned, but there was no evidence for any anisotropy – the flux did not alter when the detector scanned either the galactic plane or the plane of the ecliptic. This experiment was subsequently repeated (Houck and Harwit, 1969a) with similar results. [A later recalibration, however, (Harwit *et al.*, 1970) led the experimenters to reduce the estimated energy density by a factor ~ 2 from the 20 eV cm^{-3} originally quoted.] The detectors flown in these two rocket experiments had a flat response over the whole range 0.4–1.3 mm and so provided no spectral information. A group working at MIT (Muehlner and Weiss, 1970) recently measured the background at balloon altitudes, and obtained a similar 'excess' flux, apparently originating beyond the atmosphere and again displaying no anisotropy. These workers achieved a certain amount of spectral resolution by using three different windows. Their data were claimed to be consistent with the radiation being concentrated in a narrow band between 0.8 and 1 mm. If this indeed were the case, then neither this result, nor the results of the NRL-Cornell groups, would conflict with the present molecular limits.

In view of the difficulty in carrying out and interpreting these millimetre measurements, the present data should perhaps be treated with a certain caution. They certainly cannot claim the same accuracy as the radiometer measurements at centimetre wavelengths. Nor can an origin within the solar system be ruled out. If this intense radiation were indeed universal, it would play a role in many astrophysical processes involving high energy particles and photons, in addition to its cosmological importance. One must hope that these observations will soon be repeated, since so much hangs on them. (Though the rider should be added that repetition is equally desirable for *all* the microwave background measurements – those that accord with common prejudices as well as those that do not.)

Despite this cautionary note, I wish to discuss various interpretations of the centimetre and millimetre background on the assumption that *all* the experiments are correct, and that a flux with the measured intensity and spectrum pervades the whole universe. It may be an interesting exercise to try and appraise all the data with a fresh mind, since conventional attitudes have been conditioned, and perhaps distorted, by the *order* in which the evidence accumulated.

Rival theories of the microwave background are all severely constrained by the following three pieces of information:

(1) Colossal energetic requirements must be fulfilled. The measured energy density is ≈ 10 eV cm^{-3}. Most of this is in the millimetre band, and it compares with 0.25 eV cm^{-3} for a 2.7 K black body, and with $\approx 10^{-2}$ eV cm^{-3} for the intergalactic starlight background. If this radiation were generated at a redshift z^* from the matter, then rest energy would have to be released, and converted into the appropriate form, with an efficiency

$$\varepsilon \approx 10^{-3}\left(\frac{\varrho_0}{10^{-29}\ \mathrm{g\ cm^{-3}}}\right)^{-1}(1+z^*) \tag{1}$$

where ϱ_0 is the present mean density of the universe.

(2) The observations from 8.5 mm down to 74 cm are consistent with a ν^2 spectrum.* If the spectrum were a power law the error amounts to less than 0.05 in the spectral index. This spectrum is obviously reminiscent of a Rayleigh-Jeans law, and strongly suggests a thermal emission mechanism. Shortward of 8 mm the spectrum is not well determined.

(3) A third constraint is set by the isotropy data on small angular scales. Conklin and Bracewell (1967) found an upper limit $\approx 0.2\%$ to the intensity fluctuations on angular scales comparable with their telescope beamwidth (10 arc min). Penzias *et al.* (1969) obtained a somewhat less sensitive result at 3.3 mm. (Limits of comparable precision have also been placed on large scale anisotropies, but these constitute constraints on the cosmological model rather than on the actual emission mechanism.)

I shall critically examine three classes of interpretation: (a) those according to

* The Princeton group (Stokes *et al.*, 1967) claimed that their 8.56 mm observation was sufficiently accurate to discriminate between a ν^2 spectrum and a true black body, and that it favoured the latter. The 3 mm observation by the same group (Boynton *et al.*, 1968) was less accurate because of the atmospheric contribution, which was an order of magnitude *larger* than the expected cosmic background. (The corresponding atmospheric optical depth is $\sim 5\%$, which would not, of course, have precluded observations of strong discrete sources.)

which all the radiation is 'primeval', but the spectrum has been distorted from a true black body as a consequence of dissipative processes at pre-galactic epochs; (b) theories which attribute the background to a population of discrete sources; and (c) theories involving thermal emission by dust grains.

A. THE INHOMOGENEOUS FIREBALL

In the 'canonical' hot big bang universe, which expands isotropically and remains strictly homogeneous, the only expected deviation from a strict black body spectrum is an insignificant enhancement on the high frequency (exponential) extremity. This occurs because, during the recombination era, the ionization level remains higher than that given by the Saha equation (Peebles, 1968). In fact the universe is not, and could not ever have been, strictly homogeneous. Furthermore, the absence of neutral hydrogen in intergalactic space, inferred from studies of QSO spectra, means that the intergalactic gas cannot have cooled uninterruptedly along its initial adiabat. The required heat input could be provided by discrete sources, or maybe at an earlier epoch by dissipation of motions associated with initial inhomogeneities. In this more general, but more realistic, cosmology, the relict radiation may have a more complex spectrum, perhaps very different from the canonical black body. For example, the present background might comprise contributions from regions of space where the initial conditions were very different. Such a radiation field would resemble a superposition of Planck spectra with different temperatures – it would follow a Rayleigh-Jeans law at low frequencies, but would have a flatter peak, and a longer high frequency tail, than any black body. Of course the isotropy (3 above) constrains the permissible scale and amplitude of such inhomogeneities.

Weymann (1966a) and Zeldovich and Sunyaev (1969) have calculated the distortions of the relict radiation spectrum which would arise if energy were injected into the primeval plasma (which is treated as homogeneous). During the fireball phase, two distinct processes couple the plasma to the radiation field – free-free emission and absorption, and Compton scattering. The rates at which these processes can exchange energy between the gas and the radiation field depend respectively on $\varrho^2 T^{1/2}$ and ϱT. Thus the relative importance of the Compton effect increases during the expansion. At very early epochs when $T \gtrsim 10^6$ K, the free-free process is effective enough to guarantee establishment of a black body spectrum at the same temperature as the gas. Thus, any energy injected during these epochs would be completely thermalised,* leaving no trace in the present spectrum. (In such cases, however, the early universe would have evolved along a different adiabat. This would affect helium production, and modify the neutrino density and other present day parameters of

* If the universe expanded much faster than the standard Friedman models, then the ability to thermalize radiation would be lost at an even earlier stage. Peebles (1970) has considered homogeneous cosmologies in which the expansion timescale is drastically shortened by the effects of a scalar field. He finds that in extreme cases the relict radiation could *never* have been properly thermalised, and in some other cases the photons arising from electron–positron pair annihilation could produce a millimeter 'excess'.

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the model.) At later stages ($T \lesssim 10^6$ K), Compton scattering takes over as the main coupling between gas and radiation, though free–free emission remains important for photons at frequencies $\ll kT/h$. Leaving aside higher order effects (which are unimportant when $h\nu \ll m_0c^2$) this process leaves the photon number unaltered. Thus, if energy is injected during this later stage, the existing photons will be heated, but free–free emission cannot necessarily generate enough *new* photons to produce a black body spectrum with the higher temperature appropriate to the enhanced energy density.

Compton scattering alone leads to an equilibrium spectrum of the form $I(\nu) \propto \propto \nu^3 (e^{(h\nu/kT)+\alpha} - 1)^{-1}$, with $\alpha > 0$ (α would be zero for a Planck spectrum). Weymann (1966a) showed that if the universe were heated up to a high temperature at a sufficiently early epoch, the spectrum of the primeval radiation would be transformed into this shape. Since free–free emission is still important at low frequencies, however, the long wavelength part of the radiation field would be augmented, and there would thus be a kink in the cosmic background spectrum at centimetre wavelengths, which is not observed.

Zeldovich and Sunyaev (1969) calculated the form of the spectrum when the distortion is small. They showed that the energy density could be enhanced above the black body value by a factor ≈ 6 without the distortions at centimetre wavelengths exceeding the observational uncertainties. This is not quite sufficient to account for the observed millimetre 'excess'. However there may be other significant processes – for example, Lyman line radiation at redshifts $z \approx 10^4$ – which could boost the excess further, and perhaps even lead to a fairly sharp spectral peak at ≈ 1 mm.

These distortions only occur if energy is injected at very early epochs when the universe is still highly opaque. Equation (1) then shows that the energy must be primeval, and cannot be generated by the matter, even if the efficiency is 100%. One possibility is that it derives from dissipation of primeval turbulence (i.e. from the bulk kinetic energy of both matter and radiation in the fireball). One can envisage, at least in qualitative terms, a situation where smallscale turbulence is continually being dissipated, but its energy is being replenished by progressively larger scales which come within the particle horizon as the expansion proceeds. Even if the random motions involved velocities of (say) (0.1–0.5) c, it may still be legitimate to describe the overall expansion of the universe by a Friedman model.

B. DISCRETE SOURCES

The problem with this type of model is that the microwave background at centimetre wavelengths is hundreds of times greater than the estimated integrated contribution from known classes of radio source. Worse still, very few observed discrete sources, even among those revealed by high frequency surveys, actually have rising spectra resembling a Rayleigh-Jeans law. One is consequently forced to postulate a new population of intrinsically faint, but exceedingly numerous, sources with ν^2 spectra at centimetre wavelengths. Such sources could in principle dominate the integrated background, even though (because they would only be individually detectable out to small distances) they would be relatively inconspicuous in surveys.

Sciama (1966) and Hazard and Salpeter (1969), who considered this problem in the context of a steady state universe, found that the absence of observed sources which could conceivably belong to this hypothetical population implies, if the sources are uniformly distributed, that they are $\gtrsim 10^4$ times more numerous than galaxies. The only possible candidates would presumably be intergalactic objects in some way related to globular clusters (though even then their radio-active phase would have to last $\approx 10^{10}$ yr).

This restriction on the density of sources would be removed if *no* members of the population existed in our locality, either because of a 'local hole' or (in non-steady state cosmologies) because the dominant contribution came from large redshifts. In such circumstances *no* individual sources would appear in radio surveys. However a stringent constraint is still provided by the remarkable small-scale isotropy which the background displays. This aspect of the integrated source model has been discussed by Gold and Pacini (1968), Pariiski (1968), Hazard and Salpeter (1969), and (in greater generality) by Wolfe and Burbidge (1969) and Smith and Partridge (1970). Even making the most favourable assumptions regarding the z-dependence and spectrum of the sources, Smith and Partridge find that they must still be as numerous as galaxies, unless they are restricted to redshifts so large that the radiation is all scattered and isotropised by intervening intergalactic gas.*

Energetic considerations do not provide an insurmountable objection to this hypothesis. The spectrum of the sources is entirely hypothetical, and could be supposed to have the same form as the observed background spectrum. Alternatively (as discussed by Wolfe and Burbidge, 1969) each source could have a 'δ-function' spectrum, the observed background continuum being the integrated contribution from a wide range of redshifts. In the latter case, the isotropy data of Penzias *et al.*, (1969) may be more crucial than the more sensitive limits provided by Conklin and Bracewell (1967). This is because the former refer to shorter wavelengths, and thus (in this form of the discrete source model) to sources closer to us.

C. DUST MODELS

The possibility that the centimetre background could arise from thermal emission by grains was explored by Narlikar and Wickramasinghe (1967), their motivation being to incorporate the background into a steady state cosmology. In this cosmology, the main contribution would come only from redshifts $z^* \simeq 1$, and the energy requirements could be met by transforming $\approx 30\%$ of the matter in the universe from hydrogen into helium. Narlikar and Wickramasinghe envisaged large numbers of grains, either spread uniformly through intergalactic space or concentrated in localized sources,

* In all these estimates, it has been assumed that the sources are randomly distributed, and the intensity fluctuations are $\propto (N)^{-1/2}$, when N is the effective number of sources within the beam. If the sources were actually distributed in the same manner as galaxies, this would certainly lead to an *under*estimate of the fluctuations on scales up to ~ 30 mpc. (On the other hand, it is conceivable that it may lead to an *over*estimate on scales much larger than this.)

which emitted a line at a particular frequency. Integrating the contributions from all redshifts, one finds that, in the steady state model, each line is smeared out into a continuum with a ν^3 spectrum.* To mimic the Rayleigh-Jeans law, Narlikar and Wickramasinghe had to invoke several different lines, such that the particular frequencies at which the background had actually be observed *accidentally* yielded a ν^2 law, even though the predicted background was really a superposition of ν^3 spectra.** This model thus seems ad hoc in the extreme.

Alternatively, there might be sufficient intergalactic solid hydrogen to make the universe optically thick at centimetre wavelengths, out to $z \simeq 1$ (Hoyle and Wickramasinghe, 1967). If the grain temperature were $\lesssim 3$ K (which vapour pressure data indicate would necessarily be the case for solid hydrogen in near-vacuum conditions) one might hope to obtain a Rayleigh-Jeans spectrum. A serious difficulty with this idea, and also with Narlikar and Wickramasinghe's suggestion, is that grains radiate very inefficiently at wavelengths much larger that their own dimensions. Field (1969b) has shown that, whatever the grains are made of, the average value of Q (the ratio of the absorption cross-section to the geometrical cross-section) over any band with $\Delta\lambda/\lambda \simeq 1$ satisfies $\bar{Q} \lesssim 4\pi^2 a/\lambda$. Thus the minimum necessary column density out to $z \simeq 1$ is independent of the grain size a. Even if *all* the mass in the universe were in the form of solid hydrogen, it is only marginally possible to obtain an optical depth $\gtrsim 1$ at wavelengths as long as ~ 10 cm.

A further constraint is that the dust must not cause too much reddening or extinction in the visible. The only circumstance in which Q_{optical} would not greatly exceed $Q_{\text{microwave}}$ would be if $a \simeq 10$ cm (i.e. 'bricks' rather than grains). The only other possibility is that the grains, though individually small, may be concentrated into large clouds which are, as a whole, completely opaque to visible light. However the microwave isotropy then sets further non-trivial constraints on the properties of these discrete clouds.

The above work has been motivated by the wish to reconcile the observed cosmic background with a steady state theory of the universe. Dust models have also been considered by Layzer (1968), a proponent of the so called 'cold universe' which expanded from a singularity but initially had zero temperature. Layzer's suggestion is that the microwave background results from radiation emitted at $z \simeq 10$ which has

*The slope of the spectrum produced by a distribution of sources emitting radiation with a δ-function spectrum depends on the cosmology. For, example, the Einstein-de Sitter model yields $\nu^{3/2}$, if the source density per comoving volume is independent of z. The only model which yields a ν^2 spectrum (without invoking source evolution) is the radiation-dominated 'flat' model for which $R(t) \propto t^{1/2}$ (Wagoner, 1969).

** If Narlikar and Wickramasinghe's suggestion were correct, it would have the amusing consequence that it would be *impossible* to determine the Earth's peculiar velocity by measuring the anisotropy of the background. This is because the inferred velocity is related to the observed intensity anisotropy by $\Delta I/I = (3-\alpha)v/c$, where α is the logarithmic slope of the background spectrum at the observing frequency. (It is in any case important to bear in mind that this procedure requires knowledge of the slope of the spectrum within the fairly narrow bandwidth of the detector, whereas all that is directly observed is the *mean* spectral index over an interval with $\Delta\nu/\nu \simeq 1$.)

been thermalised by dust. In some respects, this suggestion is not faced by such severe problems as arise in the steady state model – the column density varies (in an Einstein-de Sitter model) as $(1+z^*)^{3/2}$, and one gains a further factor $(1+z^*)$ because Field's inequality must now be applied at a shorter wavelength. On the other hand, as the grain temperature would have to exceed $2.7\ (1+z^*)$K, one must rely only on heavy elements, since solid hydrogen grains could not exist.

(In extreme Lemaître-type models, of course, it would in principle be possible to completely thermalise radiation during the 'coasting phase').

A firm assessment of the relative plausibility of the three above models must await further data on the spectrum and isotropy of the millimetre flux. If the spectrum had turned out to have *precisely* the form of a black body, this would have constituted utterly compelling evidence for the canonical big bang. The rival theories that have been proposed would lose whatever plausibility they ever possessed if – in addition to satisfying the constraints 1–3 – they were also required to reproduce, by pure coincidence, an exact black body spectrum. To some extent, therefore, the 'excess' millimetre flux weakens the case for the big bang vis a vis the alternatives. However the discrete source and dust models are both hard put to satisfy constraints 1–3, which apply irrespective of the form of the millimetre spectrum. So, at least provided that this spectrum is moderately smooth, an interpretation in terms of the primordial fireball may still be the most plausible one available. The introduction of inhomogeneities obviously, in a certain sense, detracts from the elegance of the canonical big bang concept. However, it is unclear that the assumption of strict homogeneity ever had much to recommend it beyond mathematical simplicity. It entails the remarkable presumption that different parts of the universe would commence their expansion at the same time, with the same initial entropy and space curvature, even though there was at that time no causal connexion between them. Indeed, if it could be shown that the initial irregularities required in order to distort the relict radiation spectrum could have the same amplitude and scale as those needed to account for the existence of galaxies and other agglomerations, then it would not be at all 'ad hoc' to postulate their existence. The problems with the discrete source and dust models seem so severe that it is more plausible to explain the ν^2 centimetre spectrum in terms of an early 'fireball phase' when the whole universe was dense and opaque. Consequently, the 'excess' millimetre flux does not necessarily destroy or discredit the primordial fireball scheme in general (though a millimetre 'deficit' probably would).

On the other hand, one may prefer to retain the homogeneous canonical big bang as an interpretation for the centimetre background, and attribute the 'excess' to some unrelated process (which, of course, is not required by the present data to give rise to especially precise isotropy). Setti and Woltjer (1970) propose that the 'excess' may be the integrated far infrared emission from Seyfert galaxies with $z \simeq 2$. If the 'excess' had a very sharply peaked spectrum, the only alternative to a galactic origin (such as been considered by Wagoner, 1969) would be an interpretation involving the coasting phase of a Lemaître universe.

3. Infrared and Optical Background

With the exception of a tentative measurement at $\approx 100\ \mu$ due to Houck and Harwit (1969b), only upper limits to the extragalactic component of the infrared, optical and ultraviolet backgrounds are so far available. A strong background at $\approx 100\ \mu$ would be expected as the integrated contribution from powerful extragalactic infrared sources (Kleinmann and Low, 1970), and there may be a significant contribution from interstellar grains in normal galaxies.

Measurements in the nearer infrared (1–10 μ) will be important for theories of galaxy formation. Partridge and Peebles (1967) and Weymann (1966b) have argued that young galaxies should be much brighter than those observed today, and that their integrated emission, redshifted from $z \simeq 10$, may be detectable in this waveband.

Upper limits on the extragalactic component to the starlight background (Roach and Smith, 1968) have been used by Peebles and Partridge (1967) to set a lower limit to the mean mass-to-light ratio of the 'missing mass' in the universe. They find that, for a mean smoothed-out density $\approx 10^{-29}$ g cm^{-3}, this must exceed 80 solar units. (Of course all estimates of the integrated background from sources depend not only on the assumed evolution but also on the cosmological model. In particular, the predicted background can be much higher in Lemaître-type universes). A later measurement by Lillie (1968), referring to the blue part of the spectrum, is more sensitive by a factor ≈ 2 than Roach and Smith's limit, which referred to the visual band.

4. The X-Ray Background

Between 912 Å and ~50 Å the interstellar gas is so opaque that no extragalactic radiation penetrates to us. However at wavelengths shorter than ~50 Å (i.e. energies above $\sim\frac{1}{4}$ keV) a background has been observed which is predominantly extragalactic. The observational and theoretical aspects of the X-ray background were recently reviewed elsewhere (Oda, 1970; Setti and Rees; 1970). Galactic absorption confuses the situation below 1 keV, although this soft X-ray band is especially interesting because of indications that there may be a thermal contribution to the observed flux from a diffuse intergalactic gas with temperature $\approx 10^6$ K.

Over the range 1 keV–1 MeV the background spectrum has a non-thermal character. All the observations can be fitted, to within 50% accuracy, by a single power law spectrum $g(\nu) \propto \nu^{-1}$, but there are strong suggestions of a 'break' at ≈ 30 keV, the spectral index being ≈ 0.7 below this energy, and steepening to 1 or 1.2 above. This break is an important clue to the origin of the background, and (especially if it is sharp) sets severe constraints on all theories so far proposed. Most theorists have attributed the background either to a population of powerful sources, or to inverse Compton scattering of microwave background photons in intergalactic space. Since it is difficult to account for the observed intensity in terms of processes currently occurring, it has been customary to relegate the bulk of the X-ray production to redshifts $\gtrsim 2$, where the coordinate density of potential sources could have been higher or (in the case of the inverse Compton theory) the radiation mechanism relatively more efficient.

The one recent development which I wish to mention concerns the isotropy of the X-ray background. The precision with which the background is isotropic is obviously important in (a) limiting the possible galactic contribution and (b) testing the extent to which the production must be genuinely diffuse, rather than being concentrated in a few strong sources or in clusters of galaxies. Schwartz (1970) has analysed observations in the 10–100 keV band obtained from the OSO III satellite. These provide vastly better statistics than brief rocket flights. The large scale isotropy is such that not more than 5% of the X-rays could come from a galactic halo (even if its radius were as much as 44 kpc). Also, the Earth's peculiar velocity relative to the sources of the background (i.e. relative to the cosmos as a whole) is $\lesssim 800$ km sec^{-1}. Wolfe (1970) has discussed the cosmological implications of these results in fuller detail. The fluctuations on angular scales $\approx 20°$ are found to be $\lesssim 3\%$. Wolfe and Burbidge (1970) have shown that *larger* fluctuations than this would be expected if the sources were clustered in the same fashion as galaxies, unless evolutionary effects are important.

The 10–100 keV spectrum measured by the OSO III experiment revealed clear evidence for the 'break'. This is significant, because previous observations have generally spanned a smaller range of photon energies, so that the existence of the break was merely inferred by patching together non-overlapping data on either side.

Data are still very sparse in the γ-ray region above 1 MeV. There is no reason why whatever non-thermal process is responsible for the X-ray background should not continue to operate at these higher energies. However, other processes may also contribute to the γ-ray background. Clayton and Silk (1969) have made the interesting suggestion that nuclear line emission may contribute significantly at a few MeV. Observations in this energy range (which are in practice, unfortunately, very difficult), may therefore tell us something about nucleosynthesis. If adequate spectral resolution were obtainable, it might in principle be possible to determine the redshifts at which most of the heavy elements in the universe were synthesised.

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