DISTORTION OF THE MICROWAVE BACKGROUND BY DUST FROM POPULATION III

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Abstract:
Population III has been invoked to explain the missing mass in the haloes of galaxies, the first heavy elements in our Galaxy and even to explain the whole microwave background. However there are alternative explanations for each of these phenomena. The most compelling evidence for the existence of a pregalactic generation of objects is the observed distortion of the microwave background in the millimetre range, which can be explained as radiation from Population III objects absorbed and re-emitted by dust grains. If the distortion is confirmed, we can probably conclude that the density fluctuations in the early universe were isothermal and that no neutrino can have a mass in the astrophysically interesting range 1-100 eV.

1. DISTORTION OF THE MICROWAVE BACKGROUND

The idea of a pregalactic generation of objects, Population III, was revived by White & Rees (1978) in order to explain the dark haloes of galaxies, which they suggested could be made up of 10^6 $M_\odot$ black hole remnants of Population III objects. Truran & Cameron (1974) had earlier extensively discussed the possibility that the first metals in our Galaxy were made in a pregalactic generation of massive stars. Neither of these roles for Population III is essential, though. Massive neutrinos or hypothetical particles like gravitinos (which are a natural consequence of Grand Unified Theories) can account for the missing mass. The first metals in galaxies may equally well have been made in a transient generation of massive stars early in the life of the galaxies.

The idea that the microwave background radiation might in fact be background light from pregalactic objects rather than the relic of the hot Big Bang (Rees 1978 and references therein) has always come up against the difficulty of thermalising the radiation. To do so with normal dust grains requires excessively high primordial heavy element abundances (Rowan-Robinson et al 1979). The suggestion of Narlikar et al (1976) that long graphite whiskers could provide the thermalisation

G. O. Abell and G. Chincarini (eds.), Early Evolution of the Universe and Its Present Structure, 109–112.

https://doi.org/10.1017/S0074180900038754 Published online by Cambridge University Press

has been developed further by Rana (1981) and Wright (1982), who find that very large length-to-radius ratios are required. Carr (1981) suggested that free-free absorption at early epochs ($z \sim 1000$) could provide the thermalisation provided the gas was highly clumpy, but this claim is disputed by Wright (1982). Unless a glaring inconsistency in the Big Bang predictions of the primordial abundances of ^{2}H, ^{3}He, ^{4}He, and ^{7}Li develops, these ideas do not seem very attractive.

The one role for Population III which may turn out to be essential, and which would have far-reaching implications for our ideas on the history of the early universe, is that light from Population III objects absorbed and re-emitted by dust grains can explain the distortion of the microwave background spectrum from a blackbody observed by the Berkeley group (Rowan-Robinson et al 1979, Negroponte et al 1981, Rowan-Robinson 1982). Initially Woody & Richards (1979) announced that their measurements were inconsistent with a blackbody spectrum at the 5σ level. A subsequent, more detailed analysis reduced the significance of this to 2.7σ (Woody & Richards 1981), though the distortion still appears significant when compared to the ground-based radio and molecular-line measurements. In their review Danese & de Zotta (1977) estimated that the latter implied a mean blackbody temperature

$$T = 2.73 \pm 0.05 \text{ K}$$

whereas Woody and Richards found the best blackbody fit to their data to be 2.96 K. Fig. 1 shows a comparison of two of the models of Negoponte et al (1981) with the Berkeley data and with the earlier ground-based measurements. Also included are the recent rocket measurements by Gush (1981) which show an even more drastic distortion from a blackbody form in the opposite sense to, and inconsistent with the Berkeley data. This experiment was unfortunately affected by the rocket motor moving into the field of view of the telescope: the data plotted have been corrected for the effect of this. Clearly this remarkable distortion needs to be confirmed and the inconsistency with the Berkeley data resolved. At present there seem to be four options:

(1) To believe the Berkeley data and assume that the Gush data are invalidated by calibration problems or the rocket motor incident. In this case the obsidian grain model of Negroponte et al provides an excellent fit to the observations.

(2) To believe the Gush data and assume that the Berkeley data are, for some reason, invalid. A Population III type of model would still probably be the simplest interpretation of the distortion, though the redshift at which the grains are assumed to form would need to be reduced to ~ 30. A Compton distortion (see eg Danese & de Zotta 1977) is also a possibility, though it would be expected to produce a more gradual distortion than that claimed by Gush.

(3) To suppose that each experiment is broadly correct over its range of maximum sensitivity, i.e. $\gtrsim 1$ mm for the Berkeley data and $\lesssim 1$ mm for the Gush experiment. In this case the dirty silicate model of Negroponte et al gives results broadly consistent with the observations though predicting a somewhat lower amplitude distortion than observed.

https://doi.org/10.1017/S0074180900038754 Published online by Cambridge University Press

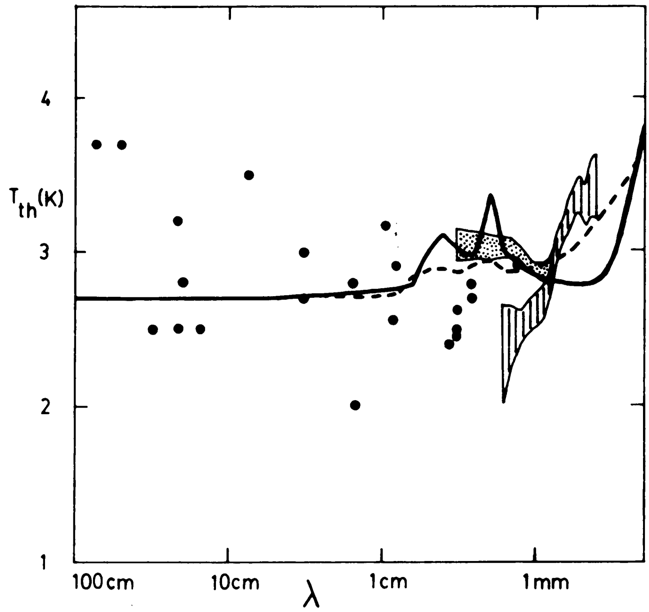

Fig.1: Microwave background spectrum, in form of plot of thermodynamic temperature against wavelength, for 2 models given by Negroponte et al (1981): solid curve, obsidian grains (z_f = 225, Z = 5 x 10^{-6}, Ω = 1), broken curve dirty silicate grains (z_f = 225, Z = 2.5 x 10^{-6}, Ω = 1). Dotted shaded area: Woody & Richards data (± 1 σ limits). Filled circles: ground-based measurements, taken from the review by Danese & de Zotta.

(4) To believe neither distortion and suppose that the microwave background spectrum is, within present observational limits, a blackbody with 2.7 K ≲ T ≲ 3.0K.

2. IMPLICATIONS OF POPULATION III

The implications of options (1) to (3) above, which seem to require the existence of Population III, are interesting because they run counter to several contemporary bandwagons.

(a) For Population III to have existed we need isothermal density fluctuations to have been present prior to the decoupling era. The natural prediction of the GUTs, however, is adiabatic fluctuations (e.g. Nanopoulos 1982), though scenarios in which isothermal fluctuations are produced can be invented (e.g. Barrow & Turner 1981).

(b) No neutrinos can have a mass in the astrophysically interesting range 1 to 100 eV, since the Jeans mass at decoupling would have been far too high for 10^6 $M_\odot$ objects to have formed (Bond et al (1980). However GUTs can supply other particles, e.g. gravitinos, to solve the missing mass problem, and these could have a high enough rest mass for the relevant Jeans mass at decoupling to be reduced to the range needed for Population III to be able to form. Both these implications lend added interest to the experiments now in progress to measure the spectrum of the background accurately in the millimetre range.

Peter Tarbet and I have been looking into the helium and heavy element yields expected from Population III stars (Rowan-Robinson & Tarbet 1982, Tarbet & Rowan-Robinson 1982). Making plausible assumptions about the mass function of the stars, mass loss and the helium and heavy element yields from the stars (which we suppose to extend from 10 to 10^6 $M_\odot$), we find that the light required to make the distortion postulated by Negroponte et al and the heavy elements needed to form the thermalising dust grains can be generated without violating observational constraints on primordial helium and heavy elements in the Galaxy, provided the mass function extends up to 10^6 $M_\odot$ accreting black holes. Models can also be found which generate the whole microwave background and the observed primordial helium. However if very massive stars ($500 \leq M/M_\odot \leq 10^5$) give a small yield of heavy elements ($\sim$ 2%) as predicted by Klapp (1982), these models generate far too high a primordial heavy element abundance.

The interesting consequences of Population III make it worthwhile to examine in more detail the astrophysics of the pregalactic era, including the interaction of Population III objects with the pregalactic interstellar medium (reionisation, Compton distortion of the background spectrum) and the possibility that the more massive of the Population III black hole remnants may gravitate to galactic nuclei to form the power house for quasars and related phenomena.

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