The Post-Recombination Universe

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The Infrared Background From Stars at High Redshift

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As emphasized by Peebles and Partridge (1967), the light of the first stars will still be present in the universe today as a faint background radiation. The expected energy density of this background, if it is generated by a population of sources which convert a fraction ϵ of their rest energy into radiation at a characteristic redshift z, may be estimated from the simple formula

$$\Omega_R = \frac{\epsilon\Omega_*}{1+z}.$$

Here Ω_* and Ω_R are the comoving mass density of the sources and the present energy density of the radiation background, both measured in units of the cosmological critical density.

For nuclear burning, $\epsilon \sim (1-3) \times 10^{-3}$ for stars above $10M_\odot$. Thus for a mass of stars comparable with the present visible mass density ($\Omega_* \sim 10^{-2}$) at a redshift of a few, we expect $\Omega_R \sim 10^{-5}$. For comparison, the observed energy density of the 2.74K blackbody microwave radiation is $\Omega_{CMB} = 1.0 \times 10^{-4}$ (Here and throughout I take $H_0 =$ 50km/s/Mpc). If the dynamical dark matter is made up of the remnants of pre- or proto-galactic massive stars (Truran and Cameron 1971, Carr, Bond and Arnett 1984), then we expect $\Omega_* = 0.1$, and $z \sim 10-50$, again predicting $\Omega_R \sim 10^{-5}$.

The observed limits on the extragalactic background light were discussed in B. Carr's paper in this volume. The most important recent development is the detection of a cosmological far infrared background by the Berkeley-Nagoya collaboration (Matsumoto et al 1987). This rocket experiment measured the spectrum of the background in six channels from 100 microns to 1100 microns. The three short wavelength channels measured the spectrum of the infrared cirrus, showing that it falls off faster than λ^{-1} at long wavelengths. The three long wavelength channels measured background radiation in a range where galactic contributions to the signal should be small, and the points show a significant departure from the black body curve. Subtracting the 2.7K blackbody (whose temperature is well determined in the Rayleigh-Jeans region) reveals an excess background between 500 microns and 1 mm, with a total energy density about 20 per cent of the microwave background, i.e. $\Omega_R \sim 2 \times 10^{-5}$.

Matsumoto et al note that simple Comptonization models cannot fit both the excess and the Rayleigh-Jeans temperature of the microwave background, although more sophisticated models may be able to (Raphaeli, in preparation). However, the excess is well fit by a simple dust emission law with a power law opacity. The peak of the excess is significantly narrower than a black body and a λ^{-2} opacity law fits well. This point is illustrated in Fig. 1 where the quantity plotted is $\Omega_R(\nu)$, the energy density per unit logarithmic frequency interval. This fit leads naturally to the interpretation of the excess as redshifted cosmological dust emission. In agreement with Matsumoto et al

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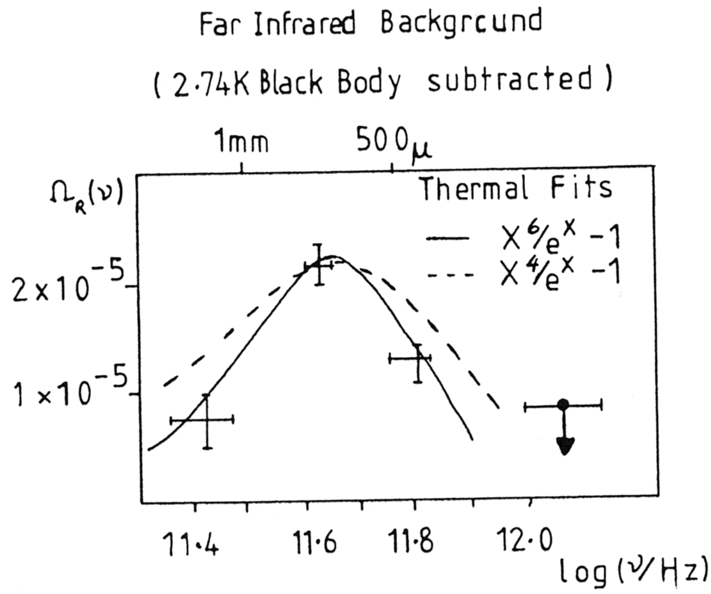

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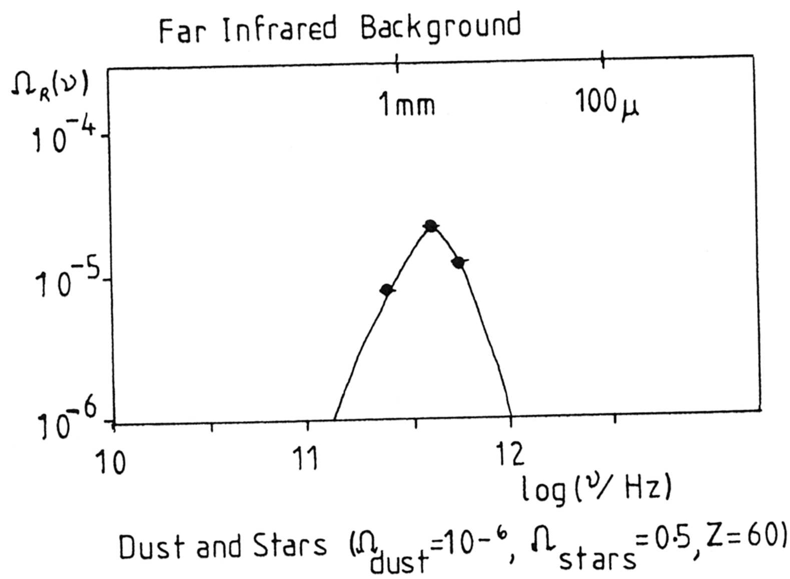

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References

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(1987), I estimate the corresponding dust temperature to be (3.55 ± 0.1)K.

Perhaps the most likely scenario for producing redshifted dust emission is one in which a 'starburst era' occurs at a redshift of 5-7, with a large fraction of all protogalaxies undergoing merger and starburst events similar to objects like NGC 3256 (Graham et al 1984). However it will be difficult to find a model in which the process occurs at a sufficiently well defined epoch to give the observed narrow peak.

A more promising possibility is the reprocessing of an ultraviolet background created at high redshift by dust in the intergalactic medium or along the line of sight. Analytic (Bond, Carr and Hogan 1986) and numerical (Negroponte 1986, McDowell 1986b) models of cosmological dust emission indicate that the expected comoving dust emission temperature remains fairly constant over a wide redshift range and predicted that a far-infrared background would be produced with a rather well defined frequency peak. However the dust temperature from these models is rather higher than observed. Matsumoto et al (1987) have interpreted their measurements of the near-IR background at 2 microns as Lyman α emission at a redshift of 15, and suggested that the far IR background could be associated with it. However, simple models suggest that extreme dust properties would be required to fit the two measurements simultaneously.

I have developed a code for studying the cosmological background radiation produced by sources of arbitrary spectra in the presence of cosmologically distributed dust (McDowell 1986a,1986b). I use an empirical Galactic dust opacity law based on the observations of Savage and Mathis (1979) and the models of Draine and Lee (1984). The resulting model spectra are integrated over the observational bandpass to compare directly with the data. Simple analytic models suggest that the best fit to the new data should be obtained using Population III massive stars at a redshift of about 100. A good fit is indeed obtained with a model in which stars with $\Omega_* = 0.5$ burn from z=95 to z=60 (corresponding to a number of stellar generations) in a universe filled with dust with a density parameter $\Omega_d = 10^{-6}$. This tiny dust density is two orders of magnitude below the maximum amount allowed by quasar reddening observations. In this model (Fig. 2) the contribution from the silicate feature (M. Rowan-Robinson, private communication) is smeared out.

Further work is required to investigate the change in dust properties needed to lower the required emission redshift and so produce a less energetically extravagant scenario.

References

Bond, J.R., Carr, B.J., and Hogan, C., 1986. *Astrophys. J.* **306**,428.

Carr, B.J., Bond, J.R., and Arnett, W.D., 1984. *Astrophys. J.* **277**,445.

Draine, B.T., and Lee, H.M., 1984. *Astrophys. J.* **285**,89.

Graham, J., Wright, G.S., Meikle, W.P.S., Joseph, R.D., and Bode, M.F., 1984. *Nature*, **310**, 213.

Matsumoto,T. , Hayakawa, S., Matsuo, H., Murakami, H., Sato, S., Lange, A.E, and Richards, P.L., 1987, preprint.

McDowell, J.C., 1986a. Ph.D. thesis, University of Cambridge.

McDowell, J.C., 1986b. *Mon. Not. R. astr. Soc.* **223**,763.

Negroponte, J.R., 1986. *Mon. Not. R. astr. Soc.* **222**,19.

Peebles, P.J.E., and Partridge, R.B., 1967. *Mon. Not. R. astr. Soc.* **148**,377.

Savage, B.D., and Mathis, J.S., 1979. *A. Rev. Astr. Astrophys.* **17**,73.

Truran, J.W., and Cameron, A.G.W., 1971. *Astrophys. Spa. Sci.* .**14**,179.

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