THE COSMIC SUBMILLIMETER BACKGROUND: A SIGNATURE OF THE INITIAL BURST OF GALAXY FORMATION?

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ABSTRACT We propose a heuristic model for the origin of the cosmic submillimeter background (SMB), reported by the Nagoya-Berkeley collaboration. The SMB is interpreted as a direct signature of an epoch of (initial) galaxy formation at $z_{gf} \sim 10 - 15$. The sources of the SMB are proposed to be dust-shrouded starburst protogalaxies, similar to the luminous *IRAS* galaxies at low redshifts. We interpret them as the progenitors of old stellar populations at low redshifts, ellipticals, bulges, and stellar components of the halos. The largest allowed time scales for the star formation in these models are in the range $FWHM \sim 0.2 - 0.6$ Gyr, for $\Omega_0 = 0.1$; for $\Omega_0 = 1$, the allowed widths are about a factor of two lower. In order not to overproduce the baryonic mass density, it is necessary that the IMF in these starbursts is biased towards high-mass stars; however, a substantial range in the IMF parameters is allowed. This postulated population of protogalaxies may be an important contributor to the diffuse soft x-ray background. The predicted surface density of protogalaxies would be in the range $\sim 10-100$ arcsec^{-2}, which is consistent with all relevant anisotropy measurements available at this time.

Recently, the Nagoya-Berkeley collaboration reported the results of a measurement of the spectrum of the cosmic microwave background (CMBR) from a rocket-borne platform (Matsumoto *et al.* 1988). They found an "excess" emission in the submillimeter wavelength region, above the level expected from the CMBR and the interstellar dust, and argued that this submillimeter background (SMB) is not caused by any instrumental effect, or any known Galactic source, and that it is most likely cosmological in origin. If this background is real, it must be very important, on account of its energetics: the energy density of SMB, $u_{\rm SMB} \simeq (9 \pm 2) \times 10^{-14}$ erg cm^{-3} is 10 – 20% that of the CMBR, $u_{\rm CMBR} = 4.26 \times 10^{-13}$ erg cm^{-3}, assuming $T_{\rm CMBR} = 2.74°$K.

The explanation for the SMB which has received most attention to date involves energy generation at a high redshift, e.g., in pregalactic (population III) stars, very massive objects, accreting pregalactic black holes, exploding cosmic strings, or some other exotic process, and its reprocessing by dust at some intermediate redshifts, e.g., $z > 3$ (Carr 1987; Rowan-Robinson and Carr 1988; Hogan and Bond 1988; Hogan 1988; Silk 1988; Adams *et al.* 1989; etc.)

Other models include comptonization of the CMBR (perhaps unlikely on the account of energetics required), decay of some hypothetical relic particles, etc.

We explore a heuristic variant of the dust-reradiation model. We propose that the sources of the SMB are similar to the low-redshift, extremely luminous far-infrared galaxies, which we tentatively identify as protogalaxies, progenitors of the present-day ellipticals and bulges, and perhaps also old disks. The SMB is thus interpreted as a signature of the epoch of *initial* galaxy formation. The advantage of our approach is in using ready-made and realistic sources of the SMB, and thus obviating the need for detialed radiation transfer computations. No new process or a previously unknown kind of objects needs to be postulated. Our intent is to explore whether such a model for the SMB can be made by using reasonable parameters, and without violating any relevant astrophysical constraints.

For the template spectra used in our models, we use fits to the observed *IRAS* data on Arp 220 and M82 in the forms $\nu B_\nu(45^\circ\mathrm{K})$, or $\nu^2 B_\nu(55^\circ\mathrm{K})$, where $B_\nu(T)$ is the Planck function. We use $\Lambda = 0$ Friedman models, with $H_0 = 75$ km s^{-1} Mpc^{-1}, and two values of the density parameter, $\Omega_0 = 0.1$ and $\Omega_0 = 1$. We represent the time history of the luminosity generated per comoving Mpc^3 as a gaussian in the rest-frame, specified by the dispersion σ^2, and the peak epoch t_c, corresponding to the redshift z_c. The flux contribution from each redshift shell is added up and normalized by fitting the final spectrum to the observed SMB data. A grid of models is computed for a range of σ and z_c, for each of the four possible combinations of the template dust spectra and Ω_0. There is a notable parameter coupling in the models, in that the larger values of σ require larger values of z_c.

We search for the longest epoch of galaxy formation which is consistent with the data. The best fits are for the lowest values of σ. However, for the $\Omega_0 = 0.1$ models, values of σ of up to $\sim (1 - 2.5) \times 10^8$ yr are compatible with the data, corresponding to the $FWHM \sim 0.2 - 0.6$ Gyr. For the $\Omega_0 = 1$ models, the allowed widths are about a factor of two lower. These time scales are comparable to the free-fall times for normal galaxies, and they are constrained primarily by the observed shape of the SMB spectrum.

In order to overproduce the cosmological density of the burned-out stars, we require that the IMF in starbursts which can generate the SMB is biased towards the more massive stars, which may be the natural mode of star formation in starbursts. Given that, a large range of possible IMF parameters is allowed. A large portion of the mass processed in the starbursts, perhaps as much as 90%, should be now locked in low-luminosity and dark stellar remnants, i.e., cool white dwarfs, neutron stars, or stellar-mass black holes. These models thus predict that the dark matter within the visible parts of galaxies should be baryonic, and consist of faint or dark stellar remnants. A similar prediction was already made by Silk (1988).

The peak luminosity densities in our models can be converted to the comoving dust densities in the mid-starburst. The later cannot exceed the amount of metals generated by that time, $\Omega_* Z$. If we associate the stellar populations generated in these bursts with the present-day metal-rich old stellar populations, their final metallicities are in the range $Z \sim (1 - 2) Z_\odot$. Thus, the plausible mid-burst metallicities are $Z \sim 0.01$. With $\Omega_* \sim 0.1$, the dust densities requred by our models are well within the allowed range.

Finally, we can estimate the expected surface density of SMB sources. For the $\Omega_0 = 0.1$ models, and sources with luminosities $L_{SMB} = f_{11} \times 10^{11} L_\odot$, the surface density requred to reproduce the observed brightness of the SMB is $85/f_{11}$ arcsec$^{-2} = 1.1 \times 10^9/f_{11}$ degree^{-2}, corresponding to the r.m.s. of $0.11\sqrt{f_{11}}$ arcsec between the sources. For the $\Omega_0 = 1$ models, the surface density is $9.4/f_{11}$ arcsec$^{-2} = 1.2 \times 10^8/f_{11}$ degree^{-2}, corresponding to the r.m.s. of $0.33\sqrt{f_{11}}$ arcsec between the sources. The SMB should thus be rather smooth on scales greater than a few arcsec. Kreysa and Chini (1988) limits at 1.3 mm and on scales $\sim$ 30 arcsec are consistent with these estimates.

It may be possible to find a spectroscopic signature of the starbursts at $z \sim 10 - 15$. Many of the commonly observed lines from the low-redshift dusty starbursts, e.g., Paα 1.875 μm, Brα 4.05 μm, or Brγ 4.05 μm, the H_2 molecular lines at 2.22 and 2.12 μm, or the PAH band at 3.3 μm may be just barely detectable with the *SIRTF*, or other future FIR/Sub-mm missions. A number of the fine structure lines of metals, e.g., [O III] 88.36 μm, [O I] 145.53 μm, or [C II] 157.74 μm would be redshifted into the atmospheric windows at millimeter wavelengths, and may be detectable with the next generation of receivers from the ground.

A population of starburst galaxies at large redshifts which can produce the SMB, could also be an important contributor to the diffuse extragalactic soft x-ray background (XRB). X-ray emission has been observed from star forming regions, and interacting galaxies (Fabbiano 1989, and references therein). The ratios of x-ray and infrared luminosities in these objects are $L_X/L_{IR} \sim (1-5) \times 10^{-4}$. The Harwit *et al.* (1987) model also predicts $L_X/L_{IR} \sim 5 \times 10^{-4}$. It may be more than a coincidence that the ratio of the energy density in the soft XRB, a few times 10^{-17} erg cm^{-3}, and that of the SMB, $\sim 10^{-13}$ erg cm^{-3}, is of the similar order.

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