small values of ε (which can be ruled out on other grounds[24]) can the required value of E_0 be brought into agreement with the observations. Furthermore, there will be a number of dead Seyfert galaxies in Lemaître models also. Each source must emit during the quasistatic period which lasts $t \approx H_0^{-1} g(1/Z_c) \left[2.2 - \frac{\ln\varepsilon}{3}\right]$ yr, thereby expending $tL_0 \sim 3\times10^{63}$ ergs (equation (11)) independent of the value of ε. Thus each galaxy must emit with an efficiency of more than 1%. For an efficiency $\alpha = 0.002$ there will be five or more dead galaxies for every active galaxy and consequently $\rho_0 \gtrsim 6\rho_{\rm gal} \sim 2\times10^{-30}$ g cm^{-3}. Because the present matter density in these models ($\lambda \sim 1$, $Z_c \gtrsim 3$) is $\leq 10^{-30}$ g cm^{-3}, α must be larger than 0.2%.

We conclude that the observed spectrum and the upper limits set on the background radiation make it exceedingly difficult to produce the sub-millimetre feature by the superposition of radiation from cosmological sources. Furthermore, there are no known sources with the required emission characteristics and evolution. Finally, an extraordinarily efficient mechanism for conversion of rest mass into infrared photons is required, particularly for low density universes. This efficiency can only be reduced for high density universes, where most of the matter resides in dead galaxies.

We have so far considered only discrete sources. Emission by the diffuse intergalactic medium, IGM, is also a possibility. Processes involving a continuum of radiation distort the black-body spectrum but cannot produce the sub-millimetre feature. In the case of line emission by the IGM (when $n(z) < (z) = E(Z)$ is the emission rate per unit co-moving volume) rapid evolution of the IGM is required because for the more favourable case of optically thin, collisionally excited unsaturated lines ($E(z) \propto$ (particle density)^2) the evolutionary function $h(Z) = Z^3$, if there is no evolution of the IGM. If the IGM is optically thick and if there is population inversion the spectrum $I(\nu) \propto e\tau$ will be sharply peaked since the optical depth τ increases with redshift. For the $\sigma_0 = q_0 - 1/2$ model, $\tau \propto (1+z)^{3/2}$ and $I(\nu) \propto \exp[\tau_0(\nu_0/\nu)^{3/2}]$ for $\nu < \nu_0$. In Lemaître models the amplification due to the maser action becomes more pronounced and $I(\nu) \propto \exp[\tau_0(\nu_0/\nu)^3/g(\nu_0/\nu Z_c)]$. Although such a process can produce a narrow spectrum, the problem of the source of the energy remains.

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[1] Stokes, R. A., Partridge, R. B., and Wilkinson, D. T., *Phys. Rev. Lett.*, **19**, 1199 (1967).
[2] Bortolet, V. J., Clauser, J. F., and Thaddeus, P., *Phys. Rev. Lett.*, **22**, 307 (1969).
[3] Hazard, C., and Salpeter, E. E., *Astrophys. J. Lett.*, **157**, L87 (1969).
[4] Smith, M. G., and Partridge, R. B., *Astrophys. J.*, **159**, 737 (1970).
[5] Shivanandan, K., Houck, J. R., and Harwit, M. O., *Phys. Rev. Lett.*, **21**, 1640 (1968).
[6] Houck, J. R., and Harwit, M. O., *Astrophys. J. Lett.*, **157**, L45 (1969).
[7] Muehlner, D., and Weiss, R., *Phys. Rev. Lett.*, **24**, 742 (1970).
[8] Peebles, P. J. E., *Astrophys. J.*, **153**, 1 (1968).
[9] Sunyaev, R. A., and Zeldovich, Ya. B., *Comments Astrophys. Space Sci.*, **2**, 66 (1970).
[10] Wagoner, R. W., *Nature*, **224**, 48 (1969).
[11] Pipher, J., Houck, J., Jones, B., and Harwit, M., *Nature*, **231**, 375 (1971).
[12] Doroshkevich, A. G., Longair, M. S., and Zeldovich, Ya. B., *Mon. Not. Roy. Astron. Soc.*, **147**, 146 (1970).
[13] Schmidt, M., *Astrophys. J.*, **151**, 393 (1968).
[14] Schmidt, M., *Astrophys. J.*, **162**, 371 (1970).
[15] Petrosian, V., *Intern. Astron. Union Symp.*, No. 44, Uppsala (Reidel, Dordecht, in the press).
[16] Petrosian, V., Bahcall, J. N., and Salpeter, E. E., *Astrophys. J. Lett.*, **155**, L57 (1969).
[17] Petrosian, V., and Salpeter, E. E., *Comments Astrophys. Space Sci.* **2**, 109 (1970).
[18] Kleinmann, D. E., and Low, F. J., *Astrophys. J. Lett.*, **159**, L165 (1970).
[19] Aumann, H. H., and Low, F. J., *Astrophys. J. Lett.*, **159**, L519 (1970).
[20] Low, F. J., and Aumann, H. H., *Astrophys. J. Lett.*, **162**, L79 (1970).
[21] Setti, G., and Woltjer, L., *Nature*, **227**, 586 (1970).
[22] Harwit, M. O., Houck, J. R., and Wagoner, V., *Nature*, **228**, 451 (1970).
[23] Petrosian, V., *Astrophys. J.*, **155**, 1029 (1969).
[24] Brecher, K., and Silk, J., *Astrophys. J.*, **158**, 91 (1969).

Neutrons in the Solar Corona

Fowler and Hashemi[1] have proposed the tempting hypothesis that neutrons constitute an energy source for the solar corona. There are, however, several important objections.

It seems very hazardous to take the upper limit of D/H on the Sun's surface to equal 4×10^{-5}. This upper limit is quoted by Kinman[2] who states that "there is no evidence for a deuterium line in the Sun". Deuterium is also more easily destroyed by thermonuclear protons than other light elements; for example, the solar abundance of lithium (Li/H$\sim10^{-11}$) is a factor of about 100 less than the solar system value (Li/H$\sim10^{-9}$ by using H/Si$=3\times10^4$). The Sun's surface must therefore be very poor in deuterium but, nonetheless, we shall adopt D/H$=4\times10^{-5}$ in the following discussion.

If one considers the subsurface thermonuclear process, the reaction $D + D = n + {}^3He$ must occur near the corona, otherwise the neutrons will be rapidly thermalized and absorbed by protons. As the corona is the hottest place in the outer region of the Sun, the highest neutron production rates are obtained inside it. The number of neutrons X_n(cm^{-3} s^{-1}) obtained by the reaction $D + D = n + {}^3He$ is calculated[3] to be

$$X_n = 6.9 \times 10^{-16} \frac{n_D^2}{2} T_9^{-2/3} \exp\left(-\frac{4.26}{T_9^{1/3}}\right)$$

where T_9 is the temperature in units of 10^9 K and n_D the density of deuterium in particles cm^{-3}.

If $T = 10^6$ K and $n_D \leq 4\times10^4$ deuterons cm^{-3} (ref. 4) then $X_n = 1.7\times10^{-24}$ neutrons cm^{-3} s^{-1}. This neutron formation rate does not explain a production of 2×10^{11} neutrons cm^{-2} s^{-1} even if the length of the solar corona is ten solar radii.

The quoted reactions $D(d,n)^3He$, $^7Li(p,n)^7Be$ and $^{14}N(p,n)^{14}O$ are not the chief possibilities because the target abundances are negligible for the two first reactions and also because the (p,n) reactions do not have such large cross sections (see, for example, the unpublished report of A. A. Caretto, 1964). The principal source of neutrons is $^4He(p,pn)^3He$, but even so[5] either the neutrons produced penetrate inside the Sun or they leave the corona before their decay because the corona is too tenuous to stop them.

For all these reasons it seems difficult to believe that neutrons constitute a valuable energy source for the corona.

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[1] Fowler, R. G., and Hashemi, J., *Nature*, **230**, 518 (1971).
[2] Kinman, T. D., *Mon. Not. Roy. Astron. Soc.*, **116**, 77 (1956).
[3] Fowler, W. A., Caughlan, G. R., and Zimmerman, B. A., *Ann. Rev. Astron. Astrophys.*, **5**, 525 (1967).
[4] Allen, C. W., *Astrophysical Quantities*, 174 (The Athlone Press, University of London, 1963).
[5] Audouze, J., *Astron. Astrophys.*, **8**, 436 (1970).