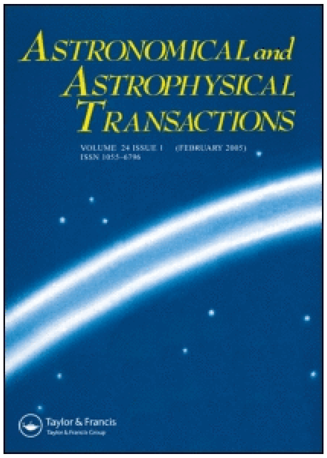

Astronomical & Astrophysical Transactions

The Journal of the Eurasian Astronomical Society

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Axion decay and the background radiation

Renato A. Dupke [a]; Mikhail V. Sazhin [a]; A. L. Sudarikov [b]
[a] Sternberg Astronomical Institute, Moscow, Russia
[b] Moscow Institute for Physics and Engineering, Moscow, Russia

Online Publication Date: 01 January 1995
To cite this Article: Dupke, Renato A., Sazhin, Mikhail V. and Sudarikov, A. L. (1995) 'Axion decay and the background radiation', Astronomical & Astrophysical Transactions, 6:3, 175 - 180
To link to this article: DOI: 10.1080/10556799508232064
URL: http://dx.doi.org/10.1080/10556799508232064

Astronomical and Astrophysical Transactions, 1995,
Vol. 6, pp. 175–180
Reprints available directly from the publisher.
Photocopying permitted by license only

AXION DECAY AND THE BACKGROUND RADIATION

RENATO A. DUPKE[1], MIKHAIL V. SAZHIN[1], and A. L. SUDARIKOV[2]

[1] *Sternberg Astronomical Institute, Moscow 119899, Russia*
[2] *Moscow Institute for Physics and Engineering, Moscow, Russia*

(Received January 26, 1993)

We analyze some effects of axion decay on the background radiation. It is suggested that, in the mass range from 1 to 5 eV, the chances of detecting the axions astrophysically are higher than in other mass ranges; such a detection could lead to the resolution of the contradictory results given by the RELIKT and COBE experiments concerning the percentage of CDM in the Universe.

KEY WORDS Background radiation, tully groups of galaxies; axion decay

INTRODUCTION

Recent observations of the anisotropies of the Microwave Background Radiation (MBR) have shown a quadrupole moment of about 10^{-6}–10^{-5} (Strukov *et al.*, 1992a,b; Smoot *et al.*, 1992; Wright, 1992; Bennett *et al.*, 1992). This is extremely important to determine several characteristics of the early and the present-day Universe. One of these aspects is the fraction of the cold and hot dark matter. Two groups, one Russian, RELIKT, and the other American, COBE, have measured the anisotropies, but they give contradictory results regarding the quantity of the cold and hot dark matter present in the Universe. The percentage of the Cold Dark Matter (CDM) varies from 80% (COBE) to 20% (RELIKT).

One possible way to explain the CDM involves axions. These particles are supposed to solve the strong CP-problem in quantum chromodynamics. At present, the mass of the axion can be found in one of two windows: from 10^{-6} eV to 10^{-3} eV or from 1 eV to 5 eV since in the other ranges, from 10^{-12} eV to 10^{6} eV they have not been found (Turner, 1991). The existence of axions leads to several interesting astrophysical and cosmological consequences. In this paper we analyze some consequences of primordial axion decay.

1 A HOMOGENEOUS AXION DISTRIBUTION

Here, we will consider a homogeneous distribution of axions with mass m_a and lifetime τ_a given by (Turner, 1991)

$$\tau_a = 6.8 \times 10^{24} \left[\frac{m_a}{\mathrm{eV}}\right]^{-5} \mathrm{s}^{-1}, \tag{1.1}$$

and assume that they decay into two photons of the same frequency, so that

$$2h\nu = m_a c^2. \tag{1.2}$$

The decay rate at a given frequency is

$$\frac{dn_\gamma}{dt} = 2n_a\Gamma_a\delta(\nu - \nu_a), \tag{1.3}$$

where n_γ and n_a are the photon and axion number densities, respectively, $\delta(\nu - \nu_a)$ is Dirac's delta function and Γ_a is equal to τ_a^{-1}.

From Equation (1.3), we see that the luminosity associated with the axion decay at redshift z is

$$dL = 2\Gamma_a h\nu(z)\delta(\nu - \nu_a(z))dN_a(z), \tag{1.4}$$

where dN_a is the number of axions between z and $z + dz$ and h is the Planck constant. The observed flux due to these axions is

$$F_a = \int \frac{2\Gamma_a h\nu_a(z)\delta(\nu - \nu_a(z))}{4\pi D_f^2(z)} dN_a(z), \tag{1.5}$$

where D_f is the photometric distance. If we consider a Universe with $\frac{\rho}{\rho_{\mathrm{crit}}} = 1$ and $P = 0$, we have (Zel'dovich and Novikov, 1975)

$$\begin{aligned} dN_a &= n_{a0}\Omega\,(c/H_0)^3 \frac{4[2 + z - 2(1+z)^{1/2}](1+z)^{1/2}}{(1+z)^3}\,dz, \\ D_f &= (2c/H_0)\,[1 + z - (1+z)^{1/2}], \\ \nu_a(z) &= \frac{\nu_0}{1+z}, \end{aligned} \tag{1.6}$$

where n_{a0} is the zero-redshift number density of axions, Ω is the solid angle and H_0 is the Hubble constant (taken as 75 km/s Mpc).

So, after some calculation we find that

$$F_a = \frac{h\nu_0 n_{a0}\Gamma_a}{2\pi}\,\Omega\,(c/H_0)\,\nu_0^{-1}\,(\nu/\nu_0)^{5/2}. \tag{1.7}$$

From Table 1 we see that the first window coincides with the MBR observational window. So, if axions have their mass at some point in the first window, we should expect some deviation from the blackbody spectrum in the MBR. Thus, we compare F_{rel} to F_a(MBR) (both fluxes/Hz).

Table 1. Characteristics of the axion decay as functions of its mass.

m_a(eV)	λ_{cm}	ν_{Hz}	τ_{a_s}	$\Gamma_{a_{\text{Hz}}}$
10^{-6}	250	1.2×10^{8}	7.1×10^{54}	1.4×10^{-53}
10^{-3}	0.25	1.2×10^{11}	7.1×10^{39}	1.4×10^{-40}
1	2.5×10^{-4}	1.2×10^{14}	7.1×10^{24}	1.4×10^{-25}
5	5×10^{-5}	6.1×10^{14}	2.3×10^{21}	4.4×10^{-22}

We assume that axions are the only component of the CDM, i.e.,

$$\rho_{\text{axion}} = \beta \frac{3H_0^2}{8\pi G} = \frac{2h\nu_0 n_{a0}}{c^2}. \tag{1.8}$$

The coefficient β can be directly taken from observations and its claimed estimates are:

$$\begin{aligned} \beta &\approx 0.8 - \text{COBE experiment}, \\ \beta &\approx 0.2 - \text{RELIKT experiment}. \end{aligned}$$

Substituting Equation (1.8) into Equation (1.7) and adopting

$$\Gamma_a = 1.4 \times 10^{-43} (\lambda_{a_{\text{cm}}}^{-5})\ \text{s}^{-1} \tag{1.9}$$

and

$$F_{\text{rel}} = 2kT\Omega\lambda_{\text{cm}}^{-2}, \tag{1.10}$$

where k is the Boltzman constant, we obtain

$$(F_a/F_{\text{rel}}) = 5 \times 10^{-20} \beta (\lambda_a/\lambda)^{1/2} \lambda_{a_{\text{cm}}}^{-2}. \tag{1.11}$$

2 AXIONS AND THE TULLY GROUPS

There is another way to look at axions. Instead of calculating the whole flux on the sky we can look for small scale fluctuations in the axion decay emission assuming that the axion distribution is not homogeneous.

Let the axions to be "trapped" by big potential wells in the Universe and the sources be distributed homogeneously and isotropically (on average) in agreement with the Poisson distribution. The average density of the sources is n_0 and the luminosity due to the axion decay is L. The observable magnitude in this case is the flux per solid angle Ω. In order to calculate F and its variance, we can divide the line-of-sight distance into intervals. Consider that the i-th interval is located between z_i and $z_i + dz$. Therefore, the line-of-sight flux is given by

$$F = \sum_i \frac{L_i}{4\pi D_{f_i}^2} n_i, \tag{2.1}$$

where n_i is the number of the sources in the solid angle Ω for the i-th interval. As the volume element is given by

$$dV = \Omega(c/H_0)^3 \xi z_i^2 \, dz, \tag{2.2}$$

where

$$\xi = \frac{4[2 + z_i - 2(1 + z_i)^{1/2}](1 + z_i)^{1/2}}{z_i^2(1 + z_i)^3},$$

so the ensemble average is given by

$$\langle n_i \rangle = n_0 \Omega (c/H_0)^3 \xi z_i^2 \, dz. \tag{2.3}$$

Summation with respect to i and ensemble averaging are commuting operations. So the average flux from a solid angle Ω can be obtained as

$$\langle F \rangle = \sum_i \frac{L_i}{4\pi D_{f_i}^2} \langle n_i \rangle. \tag{2.4}$$

In order to calculate the dispersion of the flux, we use the following simple idea: in a Poisson process, the correlation properties of the members chosen at different positions in space are described by the correlation function of the Poisson distribution, i.e., they vanish. Because of that, the "crossed" terms in

$$\langle (F - \langle F \rangle)^2 \rangle \tag{2.5}$$

for different radial intervals, or in different directions do not correlate and they vanish when they are averaged with respect to the ensemble. We have

$$\delta F^2 = \langle (F - \langle F \rangle)^2 \rangle = \sum_i \frac{L_i^2}{(4\pi)^2 D_{f_i}^4} \langle (n_i - \langle n_i \rangle)^2 \rangle. \tag{2.6}$$

Since, for a Poisson distribution,

$$\langle (n_i - \langle n_i \rangle)^2 \rangle = \langle n_i \rangle, \tag{2.7}$$

we obtain, taking into account Equation (1.6) and taking the minimal z where we find a Tully Group as 5×10^{-4},

$$\delta F^2 \approx \frac{10^3}{2\pi^2} L_0^2 n_0 \Omega (H_0/c), \tag{2.8}$$

where L_0 is the luminosity of an individual source due to the axion decay.

In order to estimate L_0, we can consider the case of a homogeneous axion distribution for a small radius ($z \ll 1$) and divide it by the number of sources, so that

$$\frac{L_{\text{total}}}{N_{\text{sources}}} = \frac{\Gamma_a h\nu_0}{m_a} \frac{H_0^2 \beta}{G} \frac{r_{\max}^3}{N_{\text{sources}}} = L_0, \tag{2.9}$$

where m_a is the axion mass. We analyze the sources like groups of galaxies and take the data from Tully's Catalog of Nearby Galaxies (Tully, 1987). In this case, we have the radius of about 25 Mpc, so that the group number density is 2.6×10^{-77} cm^{-3}. Then the luminosity of one Tully Group L_0 is

$$L_0 = 4.8 \times 10^{25} \beta \lambda_{a_{\rm cm}}^{-5} \text{ erg s}^{-1}. \tag{2.10}$$

Therefore, substituting Equation (2.10) into Equation (2.8) and using Equation (1.6), we obtain

$$\delta F \approx 1.6 \times 10^{-26} \beta \Omega^{1/2} \lambda_{a_{\rm cm}}^{-5} \text{ erg cm}^{-2} \text{ s}^{-1}, \tag{2.11}$$

and

$$F \approx \frac{\Omega}{14\pi} L_0 n_0 \Omega (c/H_0). \tag{2.12}$$

3 CONCLUSION

One possible form of the CDM is axions. Their existence could be corroborated by measuring the perturbation/contribution which photons due to the axion decay would produce in the background radiation.

In the MBR, this phenomenon could not be measured, for in Equation (1.11) we can see that even for $\lambda = \lambda_0$, $(F_a/F_{\rm rel})_{\rm max}$ would be of the order of 10^{-19}, i.e., 16 orders of magnitude smaller than what can be measured, so that the best method for searching for axions in this window is the one described by Melissinos *et al.* (1984). However, in the visible/IR range (the 2nd window), the flux due to the axion decay is relatively large when compared to the background flux and is given by

$$F_a = 3.6 \times 10^{-25} \Omega \beta \lambda_{a_{\rm cm}}^{-5} \text{ erg cm}^{-2} \text{ s}^{-1}, \tag{3.1}$$

and

$$\delta F \approx 1.6 \times 10^{-26} \Omega^{1/2} \beta \lambda_{a_{\rm cm}}^{-5} \text{ erg cm}^{-2} \text{ s}^{-1}. \tag{3.2}$$

These estimates have been obtained for the case of axions "trapped" by groups of galaxies (the Tully groups) with a Poisson distribution along distance and no intrinsic evolution. The observations in these wavelengths are very difficult to make with Earth-based instruments because of a large quantity of lines due to the emission of the night sky, especially at longer wavelengths, and they can be best done in space as planned by the Russian Orbiting Space Telescope (Kurt *et al.*, 1992).

A search for fluctuations in the visible/IR range seems to be the most promising method to test the existence (or absence) of axions and to resolve the contradictory results for the amount of CDM given by the RELIKT and COBE experiments.

ACKNOWLEDGMENTS

The authors would like to thank Prof. V. G. Kurt for providing valuable information and useful discussions, and Dr. B. P. Artamonov and L. V. Jones for helpful suggestions. This work was partially supported by the Scientific Center KOSMION grant "The Main Problems of Modern Astronomy" and the National Program for Astroparticle Physics.

References

Bennett, C. L. *et al.* (1992) *Astrophys. J.* **396**, L7.

Kurt, V. G., Stefanovich, A. E., and Sherbina, D. V. (1992) *The Scientific Apparatus ISC (Infrared Spectrometer-Camera) for the Orbiting Space Telescope T-170*, (in Russian).

Melissinos, A. C., Fowler, W. B., and Halama, H. (1984) Preprint. See also DePanfilis, S. *et al.* (1987) *Fermilab-Pub-87*, 46.

Smoot, J. F. *et al.* (1992) *Astrophys. J.* **396**, L1.

Strukov, I. A., Brukhanov, A. A., Skulachev, D. P., and Sazhin, M. V. (1992) *Pisma v Astron Zh.* (Sov. Astron. Lett.) **18**, 387.

Strukov, I. A., Brukhanov, A. A., Skulachev, D. P., and Sazhin, M. V. (1992) *Mon. Not. R. Astr. Soc.* **258**, 37–40.

Tully, R. B. (1987) *Astrophys. J.* **321**, 280.

Turner, M. (1991) Preprint.

Wright, E. L. *et al.* (1992) *Astrophys. J.* **396**, L13.

Zel'dovich, Ya. B. and Novikov, I. D. (1975) *Structure and Evolution of the Universe* (Moscow: Nauka) (in Russian).