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THE SPECTRUM OF THE EXTRAGALACTIC BACKGROUND LIGHT

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RESUMEN

El espectro observado de la Radiación de Fondo Extragaláctica en el intervalo de longitud de onda desde el ultravioleta hasta el visible es comparado con la predicción de un modelo. El modelo está construido a partir de la función de luminosidad de galaxias observada localmente, y modelos evolutivos para las distribuciones espectrales de galaxias de diversos tipos. La predicción es más baja que las observaciones, por un factor cercano a 10.

ABSTRACT

The observed spectrum of the Extragalactic Background Light in the range from ultraviolet to optical wavelengths is compared with a model prediction. The model uses the locally observed luminosity function of galaxies as well as evolutionary models for galaxy spectral energy distributions. The prediction is too faint by a factor of about 10.

Key words: **COSMIC BACKGROUND LIGHT – GALAXIES-EVOLUTION – COSMOLOGY**

I. INTRODUCTION

The Extragalactic Background Light (EBL) contains information about the past history of galaxy and star formation in the Universe. At every wavelength λ, the observed radiation results from the accumulation of the light emitted at wavelength $\lambda\ (1+z)^{-1}$ by all the galaxies at redshift z integrated over redshift. The EBL also depends on the cosmological model (q_0, H_0), since for a given local galaxy luminosity function, the number of galaxies inside a redshift shell of radius z and thickness dz, will be different for different cosmologies. How bright the galaxy was at the time at which the light was emitted is determined by the stellar evolutionary history of the particular galaxy. The relationship between time and redshift also depends on H_0 and q_0.

In most instances, theoretical models for the EBL have been computed at a single wavelength, an optical band around 5000 A, (see, for example, Stabell and Wesson 1980, and references therein). This wavelength has been preferred because of two reasons: (a) there are good observational limits of the EBL in this range (Dube *et al.* 1977), and (b) the spectra of galaxies are reasonably well known in the wavelength range that contributes the most to the EBL at 5000 A. However, galaxy spectra are much more sensitive to different star formation histories at ultraviolet wavelengths (UV) than in the optical region (Bruzual and Kron 1980; Bruzual 1981). Thus one expects the UV range of the EBL to contain most of the significant information about star formation in the Universe.

Paresce and Jakobsen (1980) have reviewed and collected all the data presently available for the diffuse UV background in the range from 900 to 5000 A (Figure 1). Bruzual and Kron (1980) and Bruzual (1981) have constructed models for the faint galaxy counts of Kron (1980). These models provide sets of evolving model galaxy spectra that reproduce both the bright and the faint end of the number galaxy counts in Kron's J-band. Since Bruzual (1981) evolving galaxy spectra cover the full spectral range, EBL predictions can be made at any arbitrary wavelength. In this paper the spectrum of the EBL expected from the Bruzual and Kron (1980) galaxy count model is computed and compared with Paresce and Jakobsen (1980) compilation.

II. MODEL

Let $f^i(\lambda, z)$ be the energy emitted per unit wavelength by a galaxy of type i at redshift z. If one observes at wavelength λ, taking into account the dilution introduced by the luminosity distance d_L (Weinberg 1972), one will receive from this galaxy an amount of energy per unit wavelength:

$$f^i\left(\frac{\lambda}{1+z}, z\right) \frac{1}{1+z} \frac{1}{4\pi\, d_L^{\,2}} , \qquad (1)$$

where the factor $(1+z)^{-1}$ takes into account the smaller wavelength interval in the galaxy reference frame.

The number of galaxies of this type inside a redshift shell of radius z and thickness dz with absolute magnitude in the range (M, M + dM) is:

$$\phi_0^i\ (M)\ (1+z)^3 \frac{dV}{dz}\ dz\ dM , \qquad (2)$$

where ϕ_0^i (M) is the locally determined number of galaxies of this type per unit volume and per unit absolute magnitude. As in Bruzual and Kron (1980) it is assumed that the shape of the luminosity function is the same for galaxies of all types i.e., $\phi_0^i(M) = \phi_0(M)$, and that the number of galaxies is conserved in time. The volume element per steradian is given by (Weinberg 1972):

$$\frac{dV}{dz} = \frac{c}{H_0} \; d_L^2 \; (1 + z)^{-6} \; (1 + 2q_0 z)^{-1/2} \; .$$

The intensity of light $I^i(\lambda)$ received at wavelength λ from this type of galaxies is obtained by multiplying (1) times (2), and integrating over all values of M and z, i. e.

$$I^i(\lambda) = \frac{c}{H_0} \; \frac{\epsilon_0^i}{4\pi} \; A^i(\lambda) \; ; \qquad (3)$$

where

$$A^i(\lambda) = \int_0^\infty \frac{f^i(\lambda/1+z\,,z)}{f^i(\lambda_0,0)} \times (1 + z)^{-4} \; (1 + 2q_0 z)^{-1/2} \; dz$$

is the accumulation factor (Jakobsen 1980) for galaxies of this type at wavelength λ. If the luminosity function $\phi_0(M)$ has been determined at wavelength λ_0, then

$$\epsilon_0^i \equiv \int_{-\infty}^{\infty} \phi_0(M) \; f^i(\lambda_0, 0) \; dM \qquad (4)$$

represents the contribution of this galaxy type to the luminosity density at wavelength λ_0.

It is customary to normalize the zero redshift galaxy spectra at $\lambda = \lambda_0$, i.e. $f^i(\lambda_0, 0) = 1$. Then (4) is independent of galaxy type and gives ϵ_0, the luminosity density at wavelength λ_0. If there are N different galaxy types, the resulting intensity of the EBL at λ is, from (3),

$$I(\lambda) = \Gamma_0 \sum_{i=1}^{N} w^i \; A^i(\lambda) \; , \qquad (5)$$

where

$$\Gamma_0 = \frac{c}{H_0} \; \frac{\epsilon_0}{4\pi} \; ;$$

w^i is the weight assigned to the galaxy class i in order to reproduce the color distribution of nearby galaxies, and is given by

$$w^i = \chi^i \; 10^{-0.4 M_i(\dagger)}$$

χ^i and $M_i(\dagger)$ are given in Tables 3 and 4 of Bruzual and Kron (1980). For Felten (1977) luminosity function

$$\Gamma_0 = 2.19 \times 10^{-9} \; \text{erg cm}^{-2}\,\text{s}^{-1}\,\text{A}^{-1}\,\text{sr}^{-1} \; ,$$

were $\lambda_0 = 4400$ A. This number is uncertain by a factor of about 1.6.

The equations presented above contain all the information required to compute $I(\lambda)$, the spectrum of the EBL. It should be pointed out that the dependence on the cosmological model (q_0) and the model galaxy spectral evolution is contained in the accumulation factor $A(\lambda)$. The dependence on H_0 only appears in the relationship between galaxy age and redshift (implicit in $A(\lambda)$). The luminosity density scales as H_0 (Felten 1977), and thus H_0 does not appear explicitly in (3).

III. RESULTS

Figure 1 shows a comparison of the predicted EBL spectrum and the observed data taken from Paresce and Jakobsen (1980). These authors present the data in the form of $I_\nu(\lambda)$ *vs.* λ. In their units, $\Gamma_0 = 2.13 \times 10^6$ eV cm^{-2} s^{-1} sr^{-1} eV^{-1}. To obtain $I_\nu(\lambda)$ from (3), the flux $f(\lambda, z)$ must be expressed per unit frequency.

The curve marked A in Figure 1 corresponds to model A of Bruzual and Kron (1980). The curve marked B uses

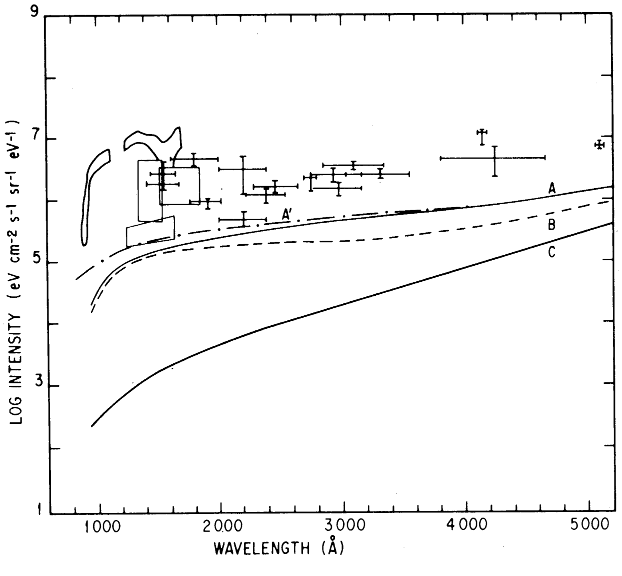

Fig. 1. Observations of the diffuse UV background at high galactic latitudes as a function of wavelength. The point at 5 100 A was taken from Dube *et al.* (1977). See Paresce and Jakobsen (1980) for comments about the source and quality of the different data points. See text for comments about the model predictions (solid lines).

the same mixture of galaxy color classes than model A, but the galaxy spectra are not allowed to evolve in time. In both cases $H_0 = 60$ km s^{-1} Mpc^{-1}, $q_0 = 0$, and galaxy age = 16 Gyr.

The flux emitted shortward of 912 A in the galaxy rest frame has been made equal to zero for both cases A and B. The curve marked A$'$ corresponds to model A when this assumption is not made. As expected, the flux emitted at $\lambda < 912$ A only affects the short wavelength region ($\lambda < 3000$ A). However, considering the uncertainty in the luminosity density ϵ_0 (0.2 in a logarithmic scale) the differences between the various $I_\nu(\lambda)$ shown in Figure 1 are not significant. Case B is fainter than case A because galaxies are fainter at any age in case B with respect to galaxy luminosities in case A.

Our predicted $I_\nu(\lambda)$ is slightly lower than Paresce and Jakobsen's $I_\nu(\lambda)$ for galaxies because they used a higher value of ϵ_0 (Jakobsen, private communication). Welch and Code (1981) prediction is in agreement with ours. The results shown in Figure 1 are essentially unchanged for other values of H_0 and q_0, or for the other models in Bruzual and Kron (1980).

All the various estimates indicate that the combined light from all the galaxies filling the universe is not enough to explain the observed intensity of the EBL. Paresce and Jakobsen (1981) have listed the more important possible sources of the diffuse background. Reflection by dust of UV light emitted by hot stars in the disk of the galaxy seems to be one of the best candidates.

The presence of dust in the galaxies or in the intergalactic medium has been neglected in these models. However, these assumptions work in the sense of increasing the background light. Thus the curves shown in Figure 1 should be considered upper limits to the contribution of galaxies to the EBL. If absorption by dust is significant (especially in the UV) one would expect some excess emission in the infrared, for which there are no data currently available.

The spectrum of the EBL is more sensitive to the type of galaxies filling the universe than to the specific cosmological model. The curve marked C in Figure 1 is the predicted $I_\nu(\lambda)$ when the four bluest galaxy types used in model A are eliminated. This choice leaves only galaxy spectra that correspond to elliptical and early type spiral galaxies. This case represents an artificial lower limit, since a large group of galaxies, bright in the UV, has been eliminated. Thus we expect the EBL to provide more information about galaxy spectra and their evolution than about q_0 and H_0. Given some assumptions about galaxy spectra, the effect of dust in the UV spectra of late type galaxies can be estimated, or at least limited, from the EBL spectrum at infrared wavelengths. This is the subject of a separate investigation (Bruzual and Jakobsen 1981).

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DISCUSSION

Fuenmayor: Resultados del satélite Einstein indican que una fracción significativa de la radiación de fondo cósmica en el intervalo de rayos X se debe a cuasares primitivos, y no a galaxias normales. ¿Qué sucede en el ultravioleta?

Bruzual: La predicción de Paresce y Jakobsen basada en esos resultados es un factor de 100 menor que las observaciones en el UV. Sin embargo, para $\lambda < 500$ A, la predicción es más alta que las observaciones.

Ferrín: ¿Podrías dar más detalles sobre el efecto de suponer que H_0 es 100 en lugar de 60 km s^{-1} Mpc^{-1}?

Bruzual: Como mencioné anteriormente, la dependencia en H_0 sólo se manifiesta implícitamente en $A(\lambda)$, a través de la relación entre edad de una galaxia y corrimiento al rojo. Si el valor de H_0 se duplica, la edad del Universo y toda la escala temporal, se dividen entre dos (para el mismo valor de q_0). A pesar de que esto implica que las galaxias en general son más azules a cualquier distancia z, la relación entre corrimiento al rojo y escala temporal es tal que efectos opuestos se cancelan. El espectro resultante $I(\lambda)$ es muy similar al mostrado en la Figura 1. Ver Bruzual (1980) para más detalles.

Campins: Es sabido que cuando nos alejamos en distancia, las galaxias son en promedio más azules. ¿Cómo se justifica el modelo en el cual sólo consideras galaxias rojas?

Bruzual: No se justifica. Es simplemente un experimento para ver cuán importante es la contribución de las galaxias azules. No debe atribuírsele realidad física.

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