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THE UV ESCAPE FRACTION OF HIGH-REDSHIFT GALAXIES

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RESUMEN

Estudiamos el grado de opacidad en el UV de galaxias a alto corrimiento al rojo. Utilizando imágenes y fotometría del HST de 27 galaxias con $1.9 < z < 3.5$, demostramos que (en promedio) no más del 4% de los fotones UV pueden escapar de éstas. Este resultado es compatible con resultados anteriores referidos a galaxias con corrimiento al rojo bajo y medio, pero contradice un resultado reciente basado en espectroscopía de galaxias a $z \approx 3$.

ABSTRACT

We investigate the degree of opacity of high-redshift galaxies to outgoing UV photons. Using multi-band images of high-redshift galaxies and HST photometry we show that *in average* no more than 4% of the continuum UV flux can escape (3σ limit) from each galaxy. This result is compatible with observations of low-redshift galaxies, but is in contradiction with some recent results based on spectroscopy of $z \approx 3$ galaxies.

Key Words: **COSMOLOGY: OBSERVATIONS — COSMOLOGY: DIFFUSE RADIATIONS**

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1. INTRODUCTION

The diffuse UV background is a key ingredient in the recipe leading to galaxy formation. Its flux has been estimated using the QSO proximity effect and the results obtained show that the flux is too large to be explained using models based on QSOs alone. Although systematic errors may make these measurements uncertain (Pascarelle et al. 2001), several suggestions have been raised for processes that could produce the observed extra flux, including the escape of a large flux of UV photons from high-redshift galaxies. This implies that the interstellar medium in these high-redshift galaxies has to be at least partially transparent to UV photons. However, the best measurements available at low and moderate redshift show that galaxies are (at least nearly) opaque to Lyman limit photons. The large column densities of neutral hydrogen expected in galaxies should be enough to very effectively quench any outgoing UV flux. In fact, Leitherer et al. (1995) find at $\langle z \rangle \approx 0.02$ a limit to the escape fraction $f_{\rm esc} < 0.0095 - 0.15$. Hurwitz et al. (1997) use the same data to derive $f_{\rm esc} < 0.032 - 0.57$. Deharveng et al. (2001) find a more stringent limit on a starburst galaxy at $z = 0.0448$, $f_{\rm esc} < 0.064$. At higher redshifts ($z \approx 1$) Ferguson (2001) finds similar upper limits $f_{\rm esc} < 0.20$.

A recent paper by Steidel, Pettini & Adelberger (2001) presents results based on an average spectrum of 29 galaxies at $\langle z \rangle = 3.40$ that apparently contradict the observations mentioned above. The authors estimate an escape fraction $f_{\rm esc} \gtrsim 0.50$. A more recent paper based on VLT spectroscopy of two high-redshift bright galaxies ($z \approx 3$, Giallongo et al. 2002) contradicts the result of Steidel et al. (2001), setting an upper limit to the escape fraction $f_{\rm esc} \lesssim 0.16(1\sigma)$. This would put the high-redshift galaxies in agreement with the observations of the local universe.

2. DATA AND METHOD

We have used in our analysis all galaxies in the HDF with spectroscopic redshift $1.9 < z < 3.5$. The lower limit is chosen so that the rest-frame Lyman limit begins to affect the F300W filter photometry, whereas the upper limit is given by the fact that the Lyman α forest becomes so dense that the effect of an intrinsic galactic Lyman-limit absorption is not noticeable. Photometry in nine bands is available for all 27 galaxies under study. We have estimated their absolute AB(1500) magnitudes (using $\Omega_\Lambda = 0.65, \Omega_{\rm M} = 0.35, {\rm H}_0 = 65$ km s^{-1}Mpc^{-1}), which range from ≈ -21.8 to ≈ -25.4.

We fit a spectral shape to the rest-frame ultraviolet range (1200 Å$< \lambda <$ 2800 Å) of each galaxy using the photometric measurements that fall within those confines. For each galaxy we fit all six templates presented in our previous photometric redshift analysis, covering four spectral types (Ell, Sbc, Scd, Irr) and two starburst models (SB1, SB2). In some cases the

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galaxies are bluer than any of the starburst models and we use a simple power law fit (of the form $f_\nu \propto \lambda^\alpha$). The choice of the best-fitting template or power-law spectrum is done based on chi-square quality-of-fit considerations.

Once a best fit spectrum is chosen for the UV region, we include the effect of the *galactic* Lyman-limit absorption, characterised by an opacity parameter τ_g whose values run from 0.01 to 100, following the usual λ^3 dependence below the Lyman limit wavelength. We then proceed to add the effect of the Lyman α forest via a simulated spectrum: to this aim we chose a standard Lyman α absorber distribution with $\beta = 1.6$, $\gamma = 2.5$. We have intensively checked the spectra generated with these parameters and they reproduce well within the observed scatter the properties of interest for us: the average absorption D_A, D_B, and the incidence of Lyman limit systems, both as functions of redshift.

After we have in this way created a "potential spectrum" of each of the objects, we measure the flux that would be observable through the F300W filter *if this were the real spectrum of the galaxy.* This process is repeated 100 times for each galaxy and each value of τ_g, and the likelihood $\mathcal{L}(\tau_g)$ is calculated by comparison with the observed value and its uncertainty.

Computing the escape fraction in this way has the advantage of a very accurate sky subtraction (we use two-dimensional images) *plus* the possibility of integrating the UV flux all over the F300W range. This represents a bandwidth of ≈ 100 Å (rest-frame) at $z \approx 3$, to be compared with the ≈ 30 over which Steidel et al. (2001) or Giallongo et al. (2002) can integrate due to the blue atmospheric cutoff.

3. RESULTS

In Figure 1 we present the results of the likelihood calculation, showing the likelihood as a function of $\log(\tau_g)$ using the complete sample. There is a sharp peak in the likelihood corresponding to $\log[\tau_g] \approx 0.7$, which converts into an escape fraction $f_{\rm esc} = 0.008$. It must be remarked that whereas the likelihood of a large escape fraction is vanishingly small ($f_{\rm esc} < 0.039, 3\sigma$ limit), the possibility of the escape fraction being zero cannot be eliminated at the 3σ level.

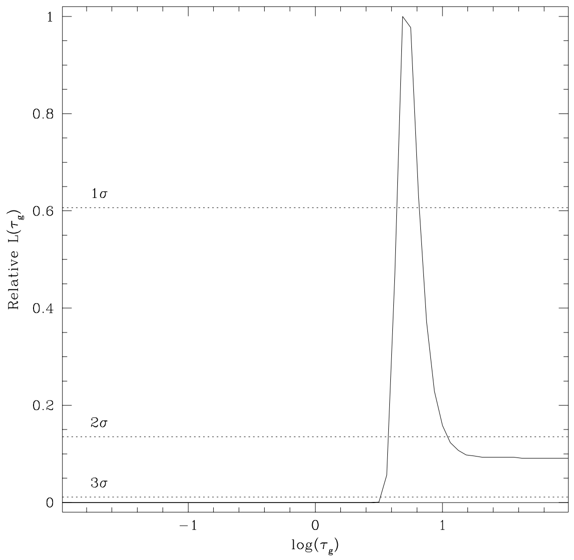

Fig. 1. Relative likelihoods of the value of τ_g. The horizontal levels correspond to statistical 1, 2, and 3 σ confidence intervals.

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