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THE SPECTRAL INDEX OF THE IONIZING CONTINUUM OF QUASARS

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RESUMEN

La distribución espectral de la energía ionizante de los cuasares muestra un cambio de pendiente por abajo de 1200 Å. El cambio del índice espectral de −1 a −2 se interpreta como una característica intrínseca de los cuasares. Estudiamos una interpretación distinta, atribuyendo este cambio a una pantalla de absorción tenue. Encontramos que la mejor función de HI con z requiere que la fracción de ionización sea independiente de la radiación de fondo metagaláctica que está congelada en ella. Ello implica que la hipotética componente tiene que tener una densidad tan baja como para que no haya habido recombinación ni enfriamiento.

ABSTRACT

The ionizing spectral energy distribution of quasars exhibits a steepening of the distribution short ward of 1200 Å. The change of the power-law index from approximately −1 to −2 so far has been interpreted as being intrinsic to quasars. We study an alternative interpretation, in which a tenuous absorption screen is responsible for the change of index. We find that the most successful function of HI with z requires that the ionization fraction be independent of the metagalactic background radiation that is frozen in. This implies that the putative component should be of sufficiently low density that it could not recombine (while the background is subsiding) and/or cool from a high temperature state.

Key Words: **ATOMIC PROCESSES — GALAXIES: INTERGALACTIC MEDIUM — GALAXIES: ACTIVE — RADIATIVE TRANSFER — ULTRAVIOLET: GENERAL**

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1. INTRODUCTION

The ionizing spectral energy distribution (hereafter ISED) of nearby active galactic nuclei cannot be observed directly, due to galactic absorption beyond the Lyman limit. Owing to the redshift effect, however, we can get a glimpse of the ISED from the spectra of very distant quasars. The pioneering work of Zheng et al. (1997, ZK97), using HST archive data, showed that the power-law index ($F_\nu \propto \nu^\alpha$) steepens from ≈ -1 for $\lambda > 1050$ Å to ≈ -2 at shorter wavelengths (combining radio-loud and radio-quiet quasars). Qualitatively similar results were found by Telfer et al. 2002 (hereafter TZ02), using a larger sample.

Korista, Ferland & Baldwin (1997) pointed out that such a steep slope for the ionizing continuum would imply a number of photons beyond $h\nu >$ 54.4 eV insufficient to account for the observed luminosities of the high excitation emission lines.

We report preliminary results of a study aimed at finding an alternative explanation for the break, one that is *extrinsic* to the quasar spectral energy distribution. We postulate the existence of a very tenuous absorption gas component that pervades the universe, and proceed to study the characteristics it must possess to reproduce the observed break.

2. PROCEDURE

The composite spectrum of ZK97 was constructed by merging 284 spectra of 101 quasars, taken with FOS of the Hubble telescope. The distribution in quasar redshifts allowed ZK97 to span the wavelength range of 310–3000 Å in the quasar rest-frame. Before merging their spectra, each spectrum was corrected for the Lyman valley and Lyα forest absorption by calculating the appropriate transmission curve, using the scheme developed by Møller & Jakobsen (1990).

Our aim is to reproduce the steepening of the index by introducing a previously unknown intergalactic absorption component. We hereby investigate how such a component can reproduce the mean composite spectrum of ZK97. Given the exploratory nature of the exercise, we can either postulate the existence of a very tenuous but continuous gas component, or a large collection of very thin discrete clouds. At any rate, these two formalisms would provide an incomplete picture if the gas distribution resembled that of the Lyα forest absorption gas (e.g. Davé et al. 1997). If the postulated component consisted of clumps, they must be sufficiently optically thin (and numerous) so as not to show up as individually detectable Lyα absorption lines in the archive FOS spectra, hence $N_{H^0} \ll 10^{12}\,\mathrm{cm}^{-2}$.

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For definiteness, we adopt a uniform gas distribution. The spectra are divided into energy bins, and for each quasar rest-frame wavelength bin j, we calculate the transmitted intensity $I^{tr}_{\lambda_j} = I_{\lambda_j} T_{\lambda_j} = I_{\lambda_j} e^{-\tau(\lambda_j)}$ by integrating the opacity along the line-of-sight to a quasar of redshift z_Q

$$\tau(\lambda_j) = \sum_{i=0}^{10} \int_0^{z_Q} \sigma_i(\tfrac{\lambda_j}{1+z})\, n_{H^0}(z) \tfrac{dl}{dz}\, dz \qquad (1)$$

where λ_j is the quasar rest-frame wavelength for bin j and $n_{H^0}(z)$ the intergalactic neutral hydrogen density. The summation was carried out over the different opacity sources: photoionization ($i = 0$) and line absorption from the Lyman series of hydrogen ($1 \leq i \leq 10$). Although our code could include up to 40 levels, we found that considering only the 10 lowest proved to be adequate. We adopted a fiducial velocity dispersion b of 30 km/s and assumed a Gaussian profile for the σ_i of the lines.

3. CALCULATIONS

After various trial and error calculations, experimenting with many different functional forms for n_{H^0}, we found that the following two distributions of HI with redshift could reproduce the composite spectrum of ZK97 quite well:

$$n_{H^0}(z) = n^0_{H^0}\, (z'_Q)^{0.8}\, (1+z)^{1.5} \quad (A)$$

$$n_{H^0}(z) = n^0_{H^0}\, (z'_Q\sqrt{z})^{0.7}\, (1+z)^3/\Gamma(z) \quad (B)$$

where z is the absorbing gas redshift, z_Q the quasar redshift, z'_Q the quasar redshift as seen from the absorbing gas at z [that is $z'_Q = (1+z_Q)/(1+z) - 1$] and $\Gamma(z)$ is the parameterized photoionization rate coefficient (Haardt & Madau 1996) due to the metagalactic ionizing radiation, but renormalized in such a way that $\Gamma(z=0) = 1$:

$$\Gamma(z) = (1+z)^{0.73} e^{-0.526((z-2.3)^2 - 2.3^2))}$$

The values of $n^0_{H^0}$ at zero redshift are $4.8 \times 10^{-12}\,\mathrm{cm}^{-3}$ and $1.35 \times 10^{-11}\,\mathrm{cm}^{-3}$ for (A) and (B), respectively. While the gas is photoionized by the metagalactic radiation in the case of (B), in (A) the neutral fraction is 'frozen in' since $\Gamma(z)$ is absent. Other factors such as the dependence on $\sqrt{z}$ in distribution (B), or the exponent of the factor $(1+z)$ (associated to its evolution during expansion of the Universe), are not superfluous but essential to the fit (and to the aim of reproducing the spectral index of $\simeq -2$ beyond 900Å). Either distribution is quite successful in reproducing the break, as shown in Fig. 1.

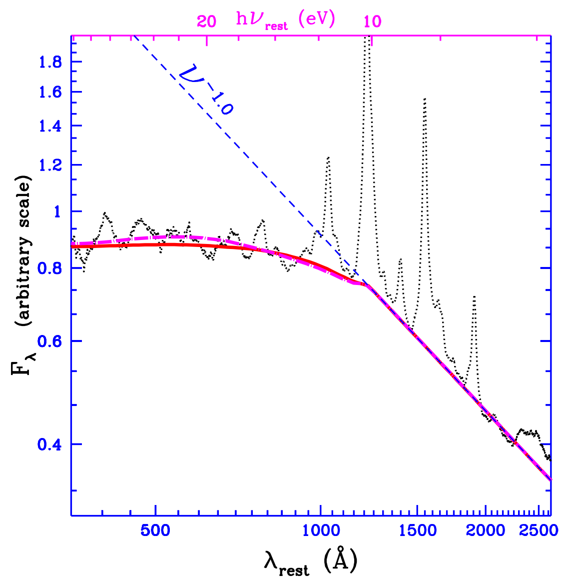

Fig. 1. The dotted line represents the composite spectrum of quasars constructed by Zheng et al. (1997), adding together both radio-quiet and radio-loud quasars. The short-dashed straight line represents a fit, in the UV range $\lambda > 1200$ Å, of the continuum underlying the emission lines ($F_\nu \propto \nu^{-1}$). The solid line is a calculated composite spectrum assuming a tenuous absorption screen of HI as given by distribution (A). The dotted long-dashed line corresponds to distribution (B).

We have assumed that the intrinsic quasar distribution exhibits no break and can be described by a single power-law $F_\nu \propto \nu^{-1}$ at all the wavelengths of interest[1]. Possible interpretations of either distribution are not straightforward, due to the presence of factors varying as z'_q. They could imply that the gas is anticorrelated with large baryonic mass accumulation (as represented by the quasar's environment) and is presumably associated with the largest voids.

The way in which we simulate the theoretical calculation of a composite spectrum is by averaging many redshifted spectral distributions as explained in more detail in Binette et al. (2002). The spectrograph wavelength window was assumed to be 3000 Å to 1300 Å which we considered typical of the wavelength coverage of individual quasars by FOS. We redshifted this window in locked steps to cover the redshift span $0.33 \leq z \leq 3.6$. Before averaging, each simulated quasar SED was multiplied by the redshift integrated transmission curve (c.f. Eqn. 1), taking into account the intervening gas described by the distribution (A) or (B). We assumed the concordance

[1] A soft ISED with $\alpha = -2$ would appear as an horizontal line segment in a LogF_λ vs. Logλ plot such as Fig. 1.

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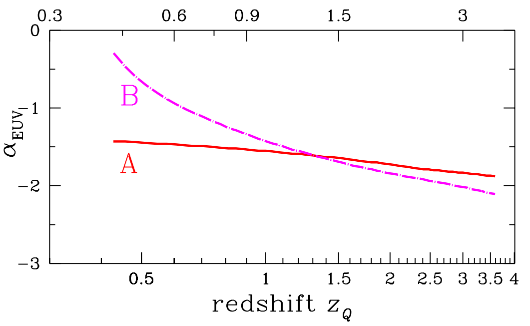

Fig. 2. Behavior of the far UV power law-index of the absorbed ISED, α_{EUV}, as a function of quasar redshift. The solid line and the dotted long-dashed lines correspond to assuming distribution (A) and (B), respectively.

ΛCDM cosmology with $\Omega_\Lambda = 0.7$, $\Omega_M = 0.3$ and $H_0 = 67\,\mathrm{km/s/Mpc}$.

4. RESULTS

The distribution (B), which takes the metagalactic background radiation into account, requires the insertion of the extra factor $\sqrt{z}$ in order to fit the observed ISED. Otherwise, the simulated spectrum curves down much too steeply at the short wavelength end. Naively, one would prefer distribution (A) with frozen-in ionization, since it is a simpler expression. A more convincing argument in favor of (A), however, is the behavior of the power-law index α_{EUV} of the transmitted ISED in the wavelength range $\lambda < 900$ Å. This is shown in Fig. 2 as a function of the quasar redshift z_Q used in the transmission function. The distribution (B) shows a significant slope for α_{EUV} while for (A) the variation is relatively small, and confined to the interval $-1.4 < \alpha_{EUV} < -1.9$.

One of the interesting result of TZ02 (c.f. their Fig. 12) is that there is no global trend of α_{EUV} as a function of redshift. The slope they found in their linear regression of α_{EUV} vs. Log z_Q was 0.09 ± 0.56 and -0.33 ± 0.66 for the populations of radio-quiet and radio-loud quasars, respectively. Considering the large dispersion in the α_{EUV} values measured, our slope of -0.52 obtained by a linear fit of the solid line in Fig. 2 cannot be ruled out (we considered radio-loud and radio-quiet quasars together), while that of distribution (B) is undoubtedly inconsistent (giving a linear fit slope of -1.71) with the TZ02 results.

If we substitute z'_Q by z in distributions (A) or (B), the flattening observed in the composite spectrum can be reproduced although it gives rise to a significant dip at 1216 Å, which is not observed. Furthermore, the behavior of α_{EUV} vs. z_Q becomes incompatible with the results of TZ02.

5. DISCUSSION

The simpler distribution (A) is in better agreement with the available data and is marginally consistent with the study of α_{EUV} by TZ02. Furthermore, it is not plagued by the two problems encountered by Binette et al. (2002), who explored different distributions of $n_{H^0}(z)$ which relied on a long range proximity effect. Interestingly, a frozen in ionization for the proposed tenuous absorption component makes sense, since it would be similar to that believed to occur in the Lyα forest at high redshift.

The fact that the frozen-in solution is favored is consistent with the tenuous absorption component being of sufficiently low density so as not to have time to recombine (as the background subsided) and/or cool from a high temperature state. If the proposed tenuous absorption component turned out to be valid, the problem of a too soft ISED as discussed by Korista, Ferland & Baldwin (1997) would go away, since the favored intrinsic index of -1 used here imply a hard ionizing spectrum in quasars.

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