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WHIM ABSORPTION AND UV QUASAR SPECTRA

Luc Binette, Sinhue Haro-Corzo and Mario Rodríguez-Martínez

Instituto de Astronomía, UNAM, 04510 D.F., México

RESUMEN

La distribución espectral de energía de cuasares presenta un empinamiento en su distribución de energía a longitudes de onda más cortas que 1200 Å. Estudiamos la posibilidad de que una componente tenue de gas intergaláctico en absorción (asociada al medio intergaláctico tibio-caliente) pudiera contribuir a una parte o a todo el empinamiento observado. Encontramos que la mayor parte del empinamiento es intrínsico a los cuasares pero que el medio intergaláctico tibio-caliente posiblemente contribuye a producir una pequeña discontinuidad en el flujo cerca de 1216 Å en el sistema inercial del observador.

ABSTRACT

The ionizing spectral energy distribution of quasars is known to exhibit a steepening in their energy distribution short-ward of 1200 Å. We study the possibility that a tenuous intergalactic absorption gas component, which we associate to the warm-hot intergalactig medium component, may contribute to all or only small part of this steepening. We find that most of the steepening is intrinsic to quasars but that the warm-hot intergalactig medium may produce a very small flux discontinuity near 1216 Å in the observer-frame.

Key Words: **GALAXIES : ACTIVE — INTERGALACTIC MEDIUM — LARGE-SCALE STRUCTURE OF THE UNIVERSE — ULTRAVIOLET: GENERAL**

1. INTRODUCTION

The composite spectral energy distribution (SED) of radio-quiet quasars derived by Telfer et al. (2002; TZ02) shows a slope break near 1200Å. The power-law index α ($F_\nu \propto \nu^{+\alpha}$) steepens from -0.72 for $\lambda \gtrsim 1200$Å to -1.57 at shorter wavelengths. The interpretation proposed was that the steepening is intrinsic to quasar and that it is the signature of a comptonized accretion disk.

A smooth distribution of intergalactic absorption gas can also cause an (apparent) steepening of the SED. Large scale structure formation models predict that a substantial fraction of baryons should reside in a warm-hot phase (WHIM) at the current epoch, possibly up to 30–40% of Ω_{bar} (Phillips, Ostriker, & Cen 2001; Davé et al. 2001, hereafter DA01). Depending on the temperature and distribution of the WHIM, this component may contribute a small fraction of the observed steepening of the quasar distribution even though most of the steepening is believed to be intrinsic to quasars as confirmed by Binette et al. (2003; BRHB hereafter). BRHB also showed that the WHIM should produce a small flux increase (that is, a discontinuity) in the region 1050–1150 Å (observer-frame) and they proposed a technique on how to set useful limits on the contribution of the WHIM to the baryonic mass.

In this contribution, we will assume that the warm-hot integalactic medium (WHIM) component, predicted by some models of large scale structure formation, can affect the transparency of the cosmos to UV radiation. We present two strong arguments, which show that most of the observed steepening is intrinsic to quasars and not due to absorption.

2. A SYNTHETIC COMPOSITE SED

We can simulate the building up of a composite SED by assuming 1) a quasar energy distribution and 2) a distribution of absorbing matter with redshift. Initially, we will assume that the intrinsic SED of quasars, from the near-UV to the far-UV, is properly described by a single powerlaw of index -0.72. We will summarize in § 7 the case where the intrinsic SED is described by a broken powerlaw that abruptly steepens at 1200 Å.

The composite SED of TZ02 was built using quasar spectra already corrected for absorption by Lyα forest absorbers. We assume that the additional absorption component (not considered by TZ02) that is postulated here is caused by an intergalactic component which decreases in density with redshift (unlike the Lyα forest which increases with redshift as $z^{2.5}$). We will associate this component to the WHIM and use the following functional form to describe it

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$$n_{H^0}(z) = n^0_{H^0}\,(1+z)^3\,\frac{\exp[-(z/1.6)^{1.4}]}{1+(z_P/z'_Q)^{1.5}} \qquad (1)$$

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 $n^0_{H^0}$ the neutral gas density at zero redshift. z_P is the size of the region (or cavity), near each quasar, within which the density decreases as $(z_P/z'_Q)^{1.5}$ towards the quasar. At large distances from the background quasar, this term becomes negligible. The exponential function in the numerator is a parametric fit of the WHIM evolution corresponding to model D2 of Davé et al. (2001). We assume the concordance ΛCDM cosmology with $\Omega_\Lambda = 0.7$, $\Omega_M = 0.3$ and $h = 0.67$ with $h = H_0/100$.

3. FITTING THE OBSERVED COMPOSITE SED

Using the above H I distribution (eq. 1), we can synthesize a composite SED by first calculating the transmission curve as a function of λ for quasars evenly space in redshift, and, then, by averaging the *transmitted* spectra of all these model-quasars. In the case of a single powerlaw intrinsic SED, the resulting synthesized SED, which closest resemble the TZ02 results, is shown in Fig. 1 (thick solid line). The parameters used in eq. 1 are $n^0_{H^0} = 5.2 \times 10^{-12}$ cm^{-2} and $z_P = 0.3$. The thin solid line describes the transmitted spectrum of an *individual* quasar of redshift $z_Q = 1.0$.

4. THE DEPENDENCE ON z'_Q

Why is the distribution of H I requires a dependence on the background quasar redshift z_Q? It turns out that distributions, which do not include a decrease of H I towards the background quasar, are characterized by a sharp break near rest-frame Lyα. The thin long-dashed line in Fig. 1 (which has $z_P = 0$) clearly illustrates the problem. The exercise proposed here would be pointless if we could not smooth out this jump. The term in denominator of eq. 1 does just that. Is there a justification for having the H I depend on z'_Q? The proximity effect in which the background quasar photoionizes further the intergalactic gas, might have been the best interpretation. However, as shown by Binette et al. (2002), the range found for this effect of the order 8 Mpc (Bajtlik, Duncan & Ostriker 1988) is much too small (i.e. the quasar flux is too small relative to the metagalactic background radiation). A possibility might be that the H I gas might be associated to large scale voids (and not to large scale mass concentrations, to which quasars may belong). In that case, the amount of absorption gas would be decreasing towards the background quasar (against which we are trying to detect it). Alternatively, the environment of quasars might be hotter and transparent as a result of (protocluster) stellar winds from the associated large scale and most massive structures.

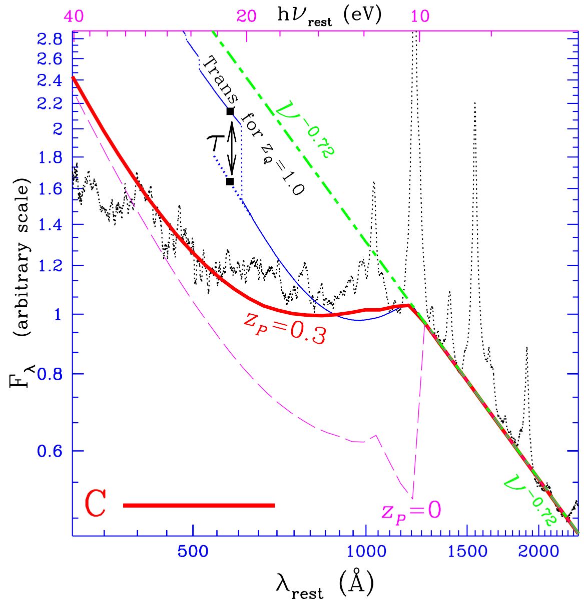

Fig. 1. The dotted-line in this F_λ vs λ_{rest} plot represents the composite spectrum of radio-quiet quasars by TZ02. The straight short-long dashed line represents a power-law fit (of index -0.72), in the longer wavelength region $\lambda > 1200$ Å (λ_{rest}) of the continuum underlying the emission lines. The thick solid line overlaying the TZ02 data is our synthetic composite Model C, which assumes a single intrinsic power-law, $F_\nu \propto \nu^{-0.72}$ and a tenuous H I absorption screen described by eq. (1) with $n^0_{H^0} = 5.2 \times 10^{-12}$ cm^{-2} and $z_P = 0.3$. The staircase thin continuous line represents the transmitted spectrum for an *individual* quasar of redshift $z_Q = 1.0$, assuming eq. (1) [same Model C] and an ideal detector with sensitivity at all wavelengths. The natural logarithm of the flux jump between the two filled squares is τ_{1160} (see definition in § 6). The thin long-dashed line illustrates the discontinuity at $\lambda_{rest} = 1216$ Å if we set z_P to zero in Model C (i.e. without cavity).

5. COMPARISON BETWEEN Lyα FOREST AND WHIM ABSORPTION

In Fig. 2, we compare the transmission function resulting from Model C with that produced by the Lyα forest. (Only a few redshifts are represented.) For spectra of intermediate resolution, in which the individual Lyα lines are not resolved (as is the case

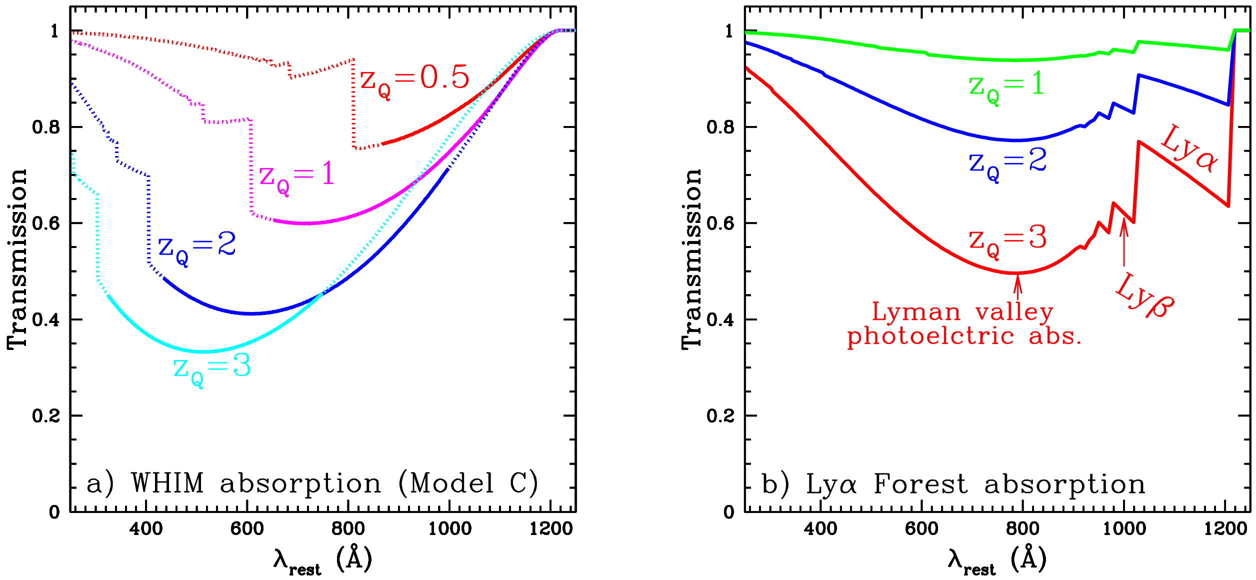

Fig. 2. Rest-frame transmission curves for quasars of representative redshifts. (*a*) using an H I absorption density corresponding to Model C. (*b*) using a distribution of Lyα forest absorbers similar to Zheng et al. (1997). The large discontinuity in each curve in Panel *a* always occurs in the observer-frame at 1216 Å.

for HST-FOS), the Lyα forest produces a substantial absorption discontinuity[1] in quasar spectra at 1216 Å (rest-frame), as illustrated in Fig. 2b. The depth of the absorption decreases towards shorter wavelengths. The onset of Lyβ absorption generates a distinct discontinuity as seen in Panel *b*. Beyond the Lyman limit (rest-frame), photoelectric absorption becomes increasingly important, creating the so-called Lyman valley near 350 Å (Møller & Jakobsen 1990). In the case, however, of an H I component behaving in a similar fashion with redshift to that predicted for the WHIM (eq. 1), we find that, at most wavelengths, the bulk of the absorption is due to Lyα scattering (see proof in BRHB). Furthermore, the absorption peak tends to occur much closer to the observer-frame Lyα rather than to the rest-frame Lyα, as shown by Fig. 2a. The largest discontinuity visible in each curve shown if Fig 2a always takes place at the wavelength of Lyα observer-frame. Note that these transmission curves do not include the Galactic Lyα absorption trough, nor the geocoronal Lyα (emission).

6. REJECTING THE STRONG VERSION OF THE ABSORPTION HYPOTHESIS

The marked steepening of the SED near 1200 Å reported by TZ02 (and Zheng et al. 1997) cannot be accounted for by H I intergalactic absorption despite the apparent qualitative agreement of Model C with the data in Fig. 1. Amongst the many reasons confirming this conclusion, we will emphasize the following two compelling reasons. First, as shown by the transmitted spectrum of individual quasars (see the $z_Q = 1.0$ model in Fig. 1), one expects to see a sharp flux jump near Lyα (observer-frame). This predicted jump could not be seen in the HST-FOS data, because its sensitivity extended only to $\sim$ 1250 Å. In the case of the more recent HST-STIS or FUSE data, however, the instrumental sensitivity does extend towards shorter wavelengths, and no such jump or discontinuity has been reported (e.g. Bowen, Tripp, & Jenkins 2001; Kriss et al. 2001, reporting on two quasars at redshifts 0.807 and 2.885, respectively). Second, the required large value of z_P of 0.3 in Model C implies such large gas cavities near each quasar that these cavities overlap each other using the known volume density of quasars. The 3D representation of eq. 1 is then unphysical given that Model C is inconsistent with the known quasar density.

It turns out that Model C implies furthermore too large a neutral fraction of hydrogen for the WHIM as discussed below. Finally, let us define the quantity τ_{1160}, which is a measure of the jump at 1200 Å (observer-frame) predicted by our various WHIM absorption models. The technique proposed consists in evaluating the discontinuity's depth

[1]TZ02 cremoved this jump by dividing their HST-FOS spectra by transmission curves similar to those shown in Fig. 2b.

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at 1160 Å ($\lambda_{obs.}$) by comparing the flux there to the extrapolated value from a power-law fit redward of Lyα ($\lambda_{obs.}$), within the narrow window 1260–1360 Å. This allows us to define the quantity $\tau_{1160} = \log_e [F^{1160}_{obs.}/F^{1160}_{extr.}]$, which can be shown to be insensitive to the power-law index assumed for quasars. The quantity τ_{1160} for Model C and a quasar of redshift unity is indicated in Fig. 1.

7. THE CASE IN FAVOR OF THE WEAK VERSION OF WHIM ABSORPTION

From the above, we conclude that the SED break reported by TZ02 is intrinsic in nature but this does not rule out that intergalactic absorption may contribute to a small fraction of the steepening. In effect, the WHIM models of Davé et al. (2001) only reveal the total hydrogen mass of the WHIM, while what we need in our calculations of the UV opacity is the mean neutral fraction of this component. Such fraction is probably a strong function of the WHIM temperature. BRHB studied the case of a broken powerlaw to describe the intrinsic SED of quasars, therefore acknowledging that most of the break is intrinsic; more specifically, by using a power-law of index α that steepens from -0.72 for $\lambda \gtrsim 1200$ Å to -1.57 at shorter wavelengths. What was found is that, if the WHIM was collisionally ionized and of temperature $\approx 10^{5.5}$ K, the expected discontinuity τ_{1160} would be of order of 1% only. Although difficult to measure, such a small discontinuity might be detectable, if we could add together a large number of EUV quasar spectra (ideally with redshifts in the range $0.5 \lesssim z_Q \lesssim 0.8$) and then extract τ_{1160} from the summed stack. Depending on whether the mean WHIM temperature is higher (or lower) than $10^{5.5}$ K, the discontinuity τ_{1160} may turn out to be smaller (or larger) than 1%. Furthermore, when τ_{1160} is that small, z_P can be set to ≤ 0.08, which allows such model to be consistent with the known quasar density.

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