SF2A 2007
J. Bouvier, A. Chalabaev, C. Charbonnel (eds)

ABSORPTION OF THE LIGHT OF QUASARS DUE TO INTER-GALACTIC NEUTRAL HYDROGEN, INTRODUCING A CORRECTION FACTOR

A. Aghaee[1,2], P. Petitjean[1], R. Srianand[3], C. S. Stalin[4] and R. Guimarães[5]

Abstract. The numerous absorption lines seen in the spectra of distant quasars (QSOs), the so-called Lyα forest, reveal the inter-galactic medium (IGM) up to redshifts larger than 6. The main goal in studying the Lyα forest in QSO spectra is to determine the underlying matter distribution in the IGM. One of the key parameters is the total amount of absorption by neutral Hydrogen. In order to measure this absorption we must first determine the QSO continuum in the Lyα forest. This is not obvious specially at low spectral resolution and high redshift where there is little unabsorbed continuum remaining in the Lyα forest. Therefore we have observed 22 high redshift highly luminous QSOs at intermediate spectral resolution, to apply the different methods of determining the QSO continuum to our QSO sample. We measured the amount of absorption, known as the flux decrement, DA, in the Lyα forest for these different methods and compared the results. This quantifies the systematic uncertainties related to the choice of the method employed to derive the continuum. By comparing measured DA from high and intermediate spectral resolution spectra, we can introduce a correction factor to be applied to the results of any automatic procedure.

1 Introduction

The IGM - which is believed to contain, at high redshift, most of the ordinary baryonic matter - and its physical properties can be studied using the imprint left in the spectra of background QSOs, the so-called Ly-α forest. Gas structures with masses as small as $1M_{\odot}$ can be detected if they are intercepted by the QSO line-of-sight.

We have observed 22 high redshift highly luminous QSOs (m ≤ 17.8 and $2.134 \leq z_{em} \leq 4.697$) at intermediate spectral resolution, with either EMMI (ESO Multi-Mode Instrument) on the ESO (European Southern Observatory) NTT (New Technology Telescope) telescope or CARELEC at the OHP (Observatoire de Haute-Provence) (see Aghaee et al. 2005, 2006). The reduction was performed using routines from the LONG MIDAS context.

2 Determination of QSO continuum

For each spectrum in our QSO sample, we have fitted the continuum using four different methods in order to compare the different results and constrain systematic errors induced by the method. One of the methods is to extrapolate in the Lyα forest the Power-Law (PL) continuum calculated over wavelengths redward of the Lyα emission line. The second method is the fully automatic Principal Component Spectra (PCS) method, in which the continuum of individual QSOs is predicted using the red side of its spectrum (see Suzuki et al. 2005). The Iterative Estimating (IE) method is another automatic method. The continuum is produced by minimising the sum of a regularisation term and a χ^2 term, which is computed from the difference between the quasar spectrum and the continuum estimated during a previous iteration (see Aracil et al. 2004). The Smooth Local

[1] Institut d'Astrophysique de Paris, UMR7095 CNRS, Université Pierre & Marie Curie, 98bis Boulevard Arago, 75014 Paris, France
[2] Department of Physics, Faculty of Science, University of Sistan and Baluchestan, 98135 Zahedan, Iran
[3] Inter University Centre for Astronomy and Astrophysics (IUCAA), Post bag 4, Ganeshkhind, Pune 411007, India
[4] Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India
[5] Observatorio Nacional - MCT, R. Gal. José Cristino 77, 20921-400 Rio de Janeiro, RJ, Brasil

(SL) method fits the continuum of a spectrum to regions of the Lyα forest deemed 'free of absorption lines' *as judged by eye*. This is done by attempting to identify unabsorbed regions within the forest and to connect them by smoothing splines.

3 Flux decrement determination

We define DA $= \langle 1 - f_i/c_i \rangle$ where f_i is the flux in pixel i and c_i is the continuum level in the same pixel. We used up to five different continua for each QSO. We averaged DA over intervals of redshift path 0.1 in the observed frame. To calculate DA in the IGM, we masked the strong DLA Lyα lines. In Figure 1 we show DA from the IGM alone as a function of redshift for different continua. The IE1 and IE2 are respectively the lowest and highest continuum obtained by changing the parameters when using the IE method. The curves are the best fit power-law DA(z) $= A(1+z)^\alpha$.

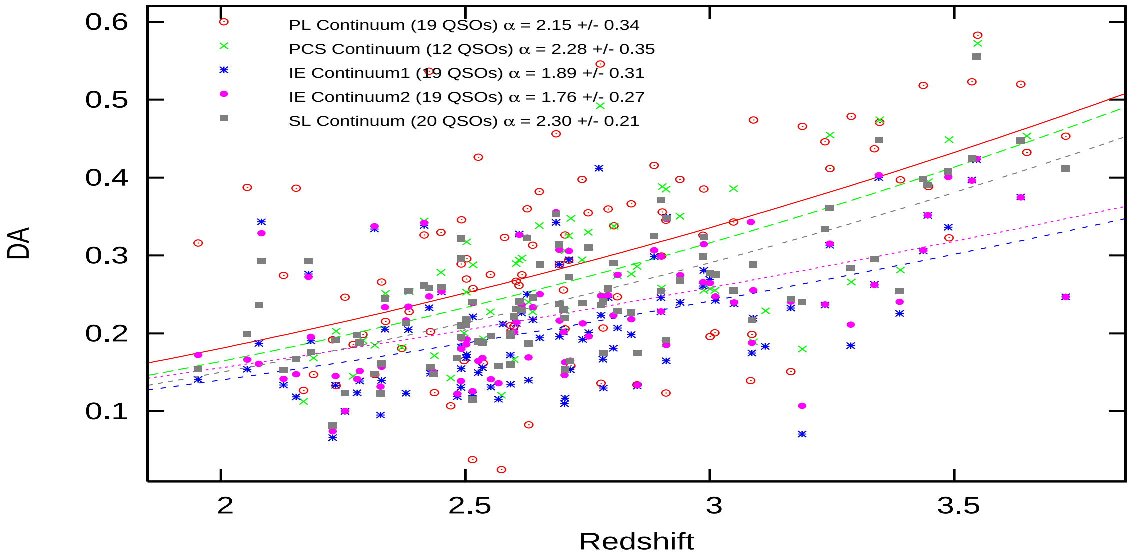

Fig. 1. DA vs. redshift, each point shows the mean DA in $\Delta z = 0.1$ for each QSO.

4 DA from high and intermediate spectral resolution spectra

In Figure 2 we show as example the reduced spectra for the same quasar observed at intermediate resolution ($R \simeq 2300$) with EMMI at the NTT and at high spectral resolution ($R \simeq 45000$) and high S/N ratio ($\sim$100 at 6000 Å) with UVES at the VLT. The QSO continua at intermediate and high spectral resolution have been obtained using the SL and IE methods, respectively.

In Figure 3 we compare DA using different methods, for the same quasars observed at both high and intermediate spectral resolution, in wavelength bins of 200Å.

5 Result

As shown in Figs 2 and 3, DA values are similar in both high and intermediate spectral resolution spectra, if we use the SL method, at least up to $z \sim 3.5$. This method should therefore be recommended. But the SL method is not an automatic method and depends on subjective decision. This problem can be overcome to a first approximation, if we make a *correction* according to the result of DA measured in Fig. 1. This correction factor should be applied to the results of an automatic method (in this paper the IE method) for data at intermediate resolution, instead of using the SL method. This correction factor is shown in Figure 4.

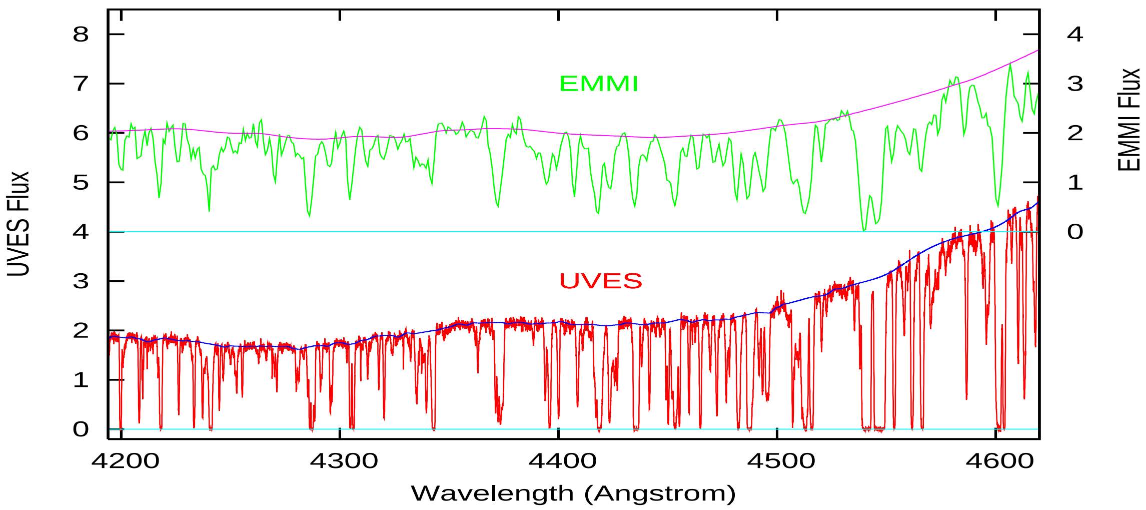

Fig. 2. HE 2347−4342 spectra at intermediate (top) and high (bottom) spectral resolution. The upper smooth curves correspond to the continua.

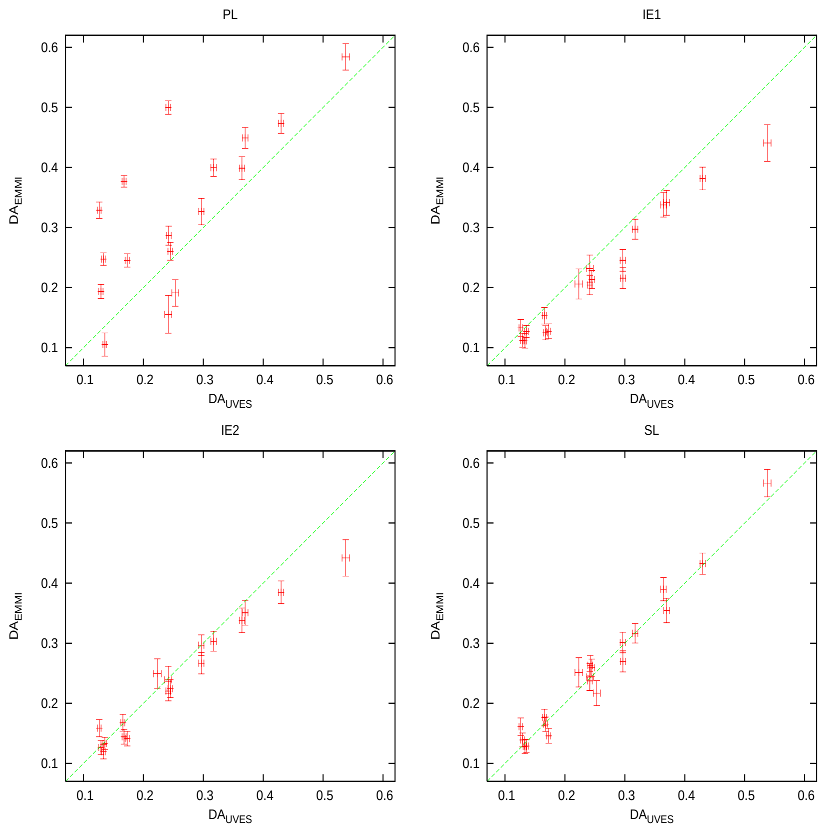

Fig. 3. DA measured from EMMI spectra and for different methods versus DA measured from UVES spectra for the same objects.

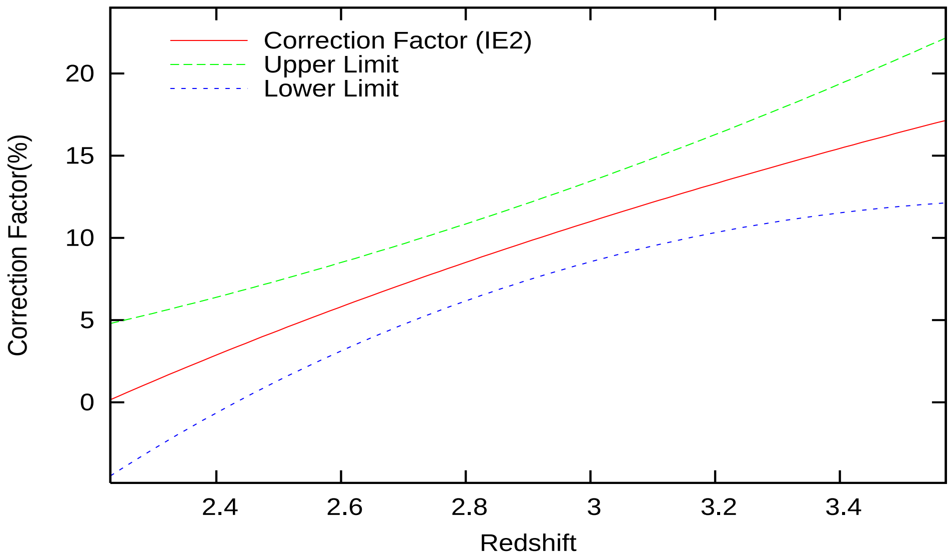

Fig. 4. The correction factor to correct the measered DA value when we use the automatic IE2 for data at intermediate spectral resolution.

References

Aghaee, A., Petitjean, P., Aracil, A., Coppolani, F., & Theuns, T. 2005, IAU Colloquium Proceedings of the International Astronomical Union, 199, 397

Aghaee, A., Petitjean, P., Stalin, C.S., Guimarães, R., & B. Aracil 2006, Proceedings of the Annual Meeting of the French Society of Astronomy and Astrophysics, 315

Aracil, B., Petitjean, P., Pichon, C., & Bergeron, J. 2004, Astron. Astrophys., 419, 811

Suzuki, N., Tytler, D., Kirkman, D., O'Meara, J. M., & Lubin, D. 2005, ApJ, 618, 592