Part 6
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Probing Galaxies through Quasar Absorption Lines
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The mean HI optical depth of the intergalactic medium

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Abstract. The intergalactic medium revealed by the numerous absorption lines seen in quasar spectra (the so-called Lyα forest) is believed to trace the potential wells of the dark matter. This is a unique tool to derive the power-spectrum of the initial fluctuations from high resolution and high S/N ratio spectra. One of the major limitations in these studies is the accuracy to which the quasar continuum is known. To investigate this problem, we have observed at intermediate spectral resolution ten bright and high redshift quasars ($2.1 < z_{em} < 4.7$) that have also been observed with UVES. We shall compare the continuum determinations for both data sets.

1. Introduction

The numerous absorption lines seen in the spectra of distant quasars, the so-called Lyα forest, reveal the intergalactic medium (IGM) up to redshifts larger than 6. The standard method to analyse the observed Lyα forest is to fit the spectra as a superposition of Voigt profiles (e.g. Carswell *et al.* 1987). The IGM is then described as a juxtaposition of discrete clouds rather than a continuous field. New methods have been implemented, however, to recover the continuum real space density distribution of the IGM by inversion of the Lyα forest (Nusser & Haehnelt 2000; Pichon *et al.* 2001). Using these new methods, it is possible to derive the statistical characteristics of the density field and therefore to determine the power spectrum of the initial perturbations which is a fundamental prediction of different cosmological theories. One major limitation of these methods is how well the continuum of the quasar is known.

2. The importance of continuum fitting

Indeed, Croft *et al.* (1999, 2002) have shown that above 12 h^{-1} Mpc, the measurement of the power spectrum is limited by uncertainties in the determination of the QSO continuum. Recently, Seljak *et al.* (2003) have demonstrated from SLOAN survey data that the uncertainty in the mean flux is currently one of the major obstacles for an accurate determination of the power spectrum.

Table 1. Observed QSOs

QSO	z_{em}
BR 1202-0725	4.697
PKS 2000-330	3.783
PKS 2126-158	3.266
HE 2347-4342	2.885
Q1511-091	2.878
Q0002-422	2.758
HE 0151-4326	2.740
HE 1347-2457	2.534
HE 2217-2818	2.406
HE 1341-1020	2.134

The latter is a crucial complement to CMB data for constraining the index of the primordial power-spectrum as well as determining the epoch of reionisation (Kogut *et al.* 2003). An accurate measurement of $\langle F \rangle$ is also crucial for constraining the nature of the sources of the UV background, and the period of reionisation. Other issues related to the physical state of the gas in the Lyα forest are also dependent on the continuum fitting, for example, the search for any deviation from Voigt-profile fitting which could have important consequences for our knowledge of the gas kinematics and thermal state (e.g. Outram *et al.* 2000).

More recently, Tytler *et al.* (2004) have presented a new method to derive the continuum in high resolution and high S/N ratio spectra. They have measured the amount of absorption, known as the flux decrement, $D_A = 1 - \langle F \rangle$, in the redshift range $1.85 < z < 2.5$.

3. Observations and data reduction

The aim of this work is to discuss the uncertainties in the continuum determination. For this, we compare the mean flux observed for the same QSOs in high and low resolution spectra. We have performed relative flux-calibration of bright quasars which have been observed with UVES in the course of the ESO Large Programme “The Evolution of the Intergalactic Medium”. In high resolution data difficulties arise from uncertainties in sky-subtraction, fitting of the background and the inter-order scattered light, and also as a consequence of difficulties in fitting the blaze function and merge orders.

Therefore, we have observed at intermediate spectral resolution, $R \simeq 5{,}600$, ten bright and high redshift quasars ($2.1 < z_{em} < 4.7$, see Table 1) with the ESO NTT telescope and EMMI from July 14th to 17th 2004.

For the lower redshifts, we have used Grating 12 in the blue arm with an exposure time of 3×1200 s in the range 3400-4300 Å and 3×900 s in the range 5300-6200 Å. For the higher redshifts, we have used Grating 7 in the red arm with an exposure time of 3×1200 s in the range 4800-6300 Å. Each image was bias and flat-field corrected using MIDAS routines. The cosmic rays were flagged using a median filter. In Fig. 1 we show an example of reduced spectra for the same quasar observed at high resolution, $R \simeq 45{,}000$, and intermediate resolution with $R \simeq 5{,}600$.

4. The next step

The next step will be to fit using different procedures the best continuum for each quasar spectrum at both high and intermediate resolutions in order to compare them

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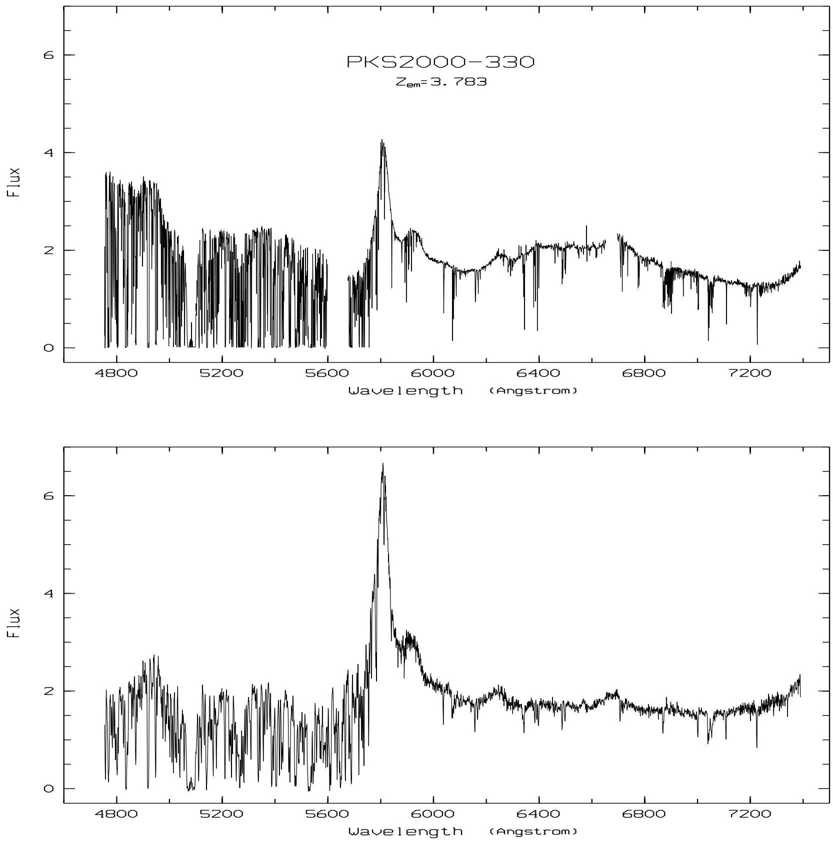

Figure 1. PKS2000−330 has been observed at high spectral resolution ($R \simeq$ 45,000) and high S/N ratio (∼100 at 6000 Å) with UVES at the VLT (top panel) and at intermediate resolution ($R \simeq$ 5,600) with EMMI at the NTT (bottom panel). Observations with different grisms are over-plotted.

and constrain systematic errors. As a result we will determine the evolution with redshift of the mean optical depth of the IGM that is needed to calibrate N-body numerical simulations.

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