Probing weak NeVIII absorption with 'agnostic stacking' of COS data

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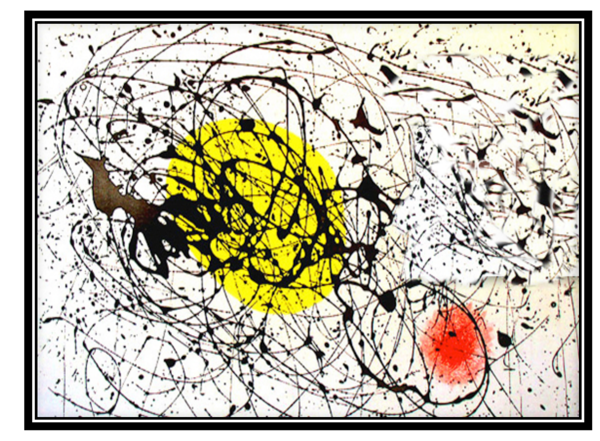

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Abstract

Utilising the largest available high-quality COS dataset towards quasars at redshifts z>0.7, we probe weak NeVIII absorbers to an unprecedented low column density limit (log N > 12.3) via a new method ('agnostic stacking'). The total pathlength for NeVIII detection (Δz = 9.3), and high S/N of the data in conjunction with this new statistical method allow us to place tight constraints for the slope and normalisation of the column density distribution function over a range of column densities not accessible to direct searches. We find that this method (with modelling of the absorber population and noise characteristics) is a powerful tool for measuring doublet absorption at the noise limit.

1. The importance of searching for weak NeVIII absorption signals

Seven-times ionised Neon (the 5th-most abundant element in the universe, ionization potential of 207 eV) is a good tracer of warm, collisionally ionized gas, although at densities $n_H < 10^{-5}$ cm^{-3} photoionization may also play a significant role in its creation (see e.g. Oppenheimer 2013). Exploiting even the best available UV-spectra has lead thus far only to a handful of direct detections of NeVIII absorbers (Savage et al. 2005, 2011a; Naryayanan et al. 2009, 2011, 2012; Tripp et al. 2011; Meiring et al. 2013, Hussain 2015), all of which require column densities log N > 13.0. Simulations predict the bulk of the NeVIII absorber population to lie between 12.0 < log N < 12.7 (Tepper-Garcia 2013, Oppenheimer 2013). Hence, we have developed a new technique to probe ***weak*** absorption distributed amongst the data with a statistical approach. This relaxes the requirement that absorbers be detected individually, opening a more numerous population hidden to traditional line searches, and circumventing potential subjectivity of identifications.

We are able to exploit the largest high-quality dataset of sightlines towards UV-bright QSOs observed with COS, analysed in coherent fashion. For details see Danforth (2014). The total pathlength suitable for NeVIII detection summed over the 25 sightlines is Δz = 9.3.

2. Introducing the 'agnostic' stack

We construct composite spectra following a new procedure: we identify all pixels in our dataset exhibiting a normalised flux between f_n = 0.88 (corresponding roughly to the flux limit associated with log N = 13.0) and an optimised maximum flux (depending on the assumptions about the absorber population) regardless of our knowledge of their nature as absorbers (hence 'agnostic'). We then treat each of these *as if they were* the strong member of the NeVIII 770/780 Å doublet, and shift the COS spectrum into the thus assumed absorber restframe. By generating the arithmetic mean of all these absorber spectra, we arrive at our 'NeVIII composite spectrum'.

Figure 1 shows our observational result : a non-detection.

If there were significant NeVIII absorption in that sample, we would expect a signal at the location of the weaker doublet member (NeVIIIb at 780 Å, indicated by the arrow in Fig. 1). Many selected pixels are likely to arise due to noise and absorption other than NeVIIIa, hence the NeVIIIb signal is expected to be diminished by the same large factor.

The apparent strength of the NeVIIIb feature combined with the deterministic doublet line strength ratio provides a direct measurement of this dilution, allowing the population to be explored with modelling.

3. Modelling to infer the significance of (non-)detection

We create model spectra matching the size of our data set, and populate them first with a set of NeVIII absorbers as follows: we generate a NeVIII absorbing population in line with our pathlength, and a normalisation and slope (β) of the column density distribution function (CDDF). We then assign b-parameters randomly between 20 < b < 40 km/s, and place them at random redshifts in our spectra, assuming them to be represented by Voigt profiles.

To these pure NeVIII spectra, we then add both additional absorption following a purely heuristic model (essentially an exponential distribution in optical depth), and noise replicating characteristics of each pixel in the real data.

We adjust the parameters of the heuristic absorption model such that a best fit for the pixel flux distribution with all three components (NeVIII absorbers, additional non-NeVIII absorption, and noise) is achieved when compared to the real dataset (illustrated in Fig 2 for an example CDDF).

After the construction of mock sets of spectra, we run exactly the same pixel selection mechanism as for real data, and hence can assess which of the NeVIII absorbers end up in the composite. Thus, we can predict the expected signal strength at NeVIIIb, and – using the error estimate measured in the real composite – its significance.

4. The meaning of the non-detection of NeVIIIb

Figure 3 is the final result of our search for weak NeVIII absorption; how meaningful is the non-detection of the NeVIIIb signature in our composites?

Note that we probe the population of absorbers below a column density limit of about log N < 13.0 (and hence our method is complementary to the traditional direct doublet searches). For a given significance level, we can constrain a combination of the normalization and the slope of the CDDF. For example, if we apply a 3σ – detection limit, all of the parameter space above the thick black line is excluded by our non-detection. We include an extrapolation from high column density systems observed directly (dotted lines) with a given power-law slope. The cyan data point in the lower left of the diagram represents the simulations of Tepper-Garcia (2103), who state that their incidence rate of strong absorbers is almost two orders of magnitude below the observed values by Meiring (2013).

Our main result is a non-detection of the weak NeVIII absorber population (12.0 < log N < 13.0). Our statistical analysis allows us to place tight limits on the slope and normalization of the CDDF for such absorbers. For example, extending the observed dn/dz for higher column density systems with slopes lower than β<-2.2 is ruled out at a signifance >3σ by our approach (cf. Fig. 3). We propose to use the same method to probe the weak absorber populations for different ionic transitions in similar fashion (e.g. OVI, MgX and SiXII)

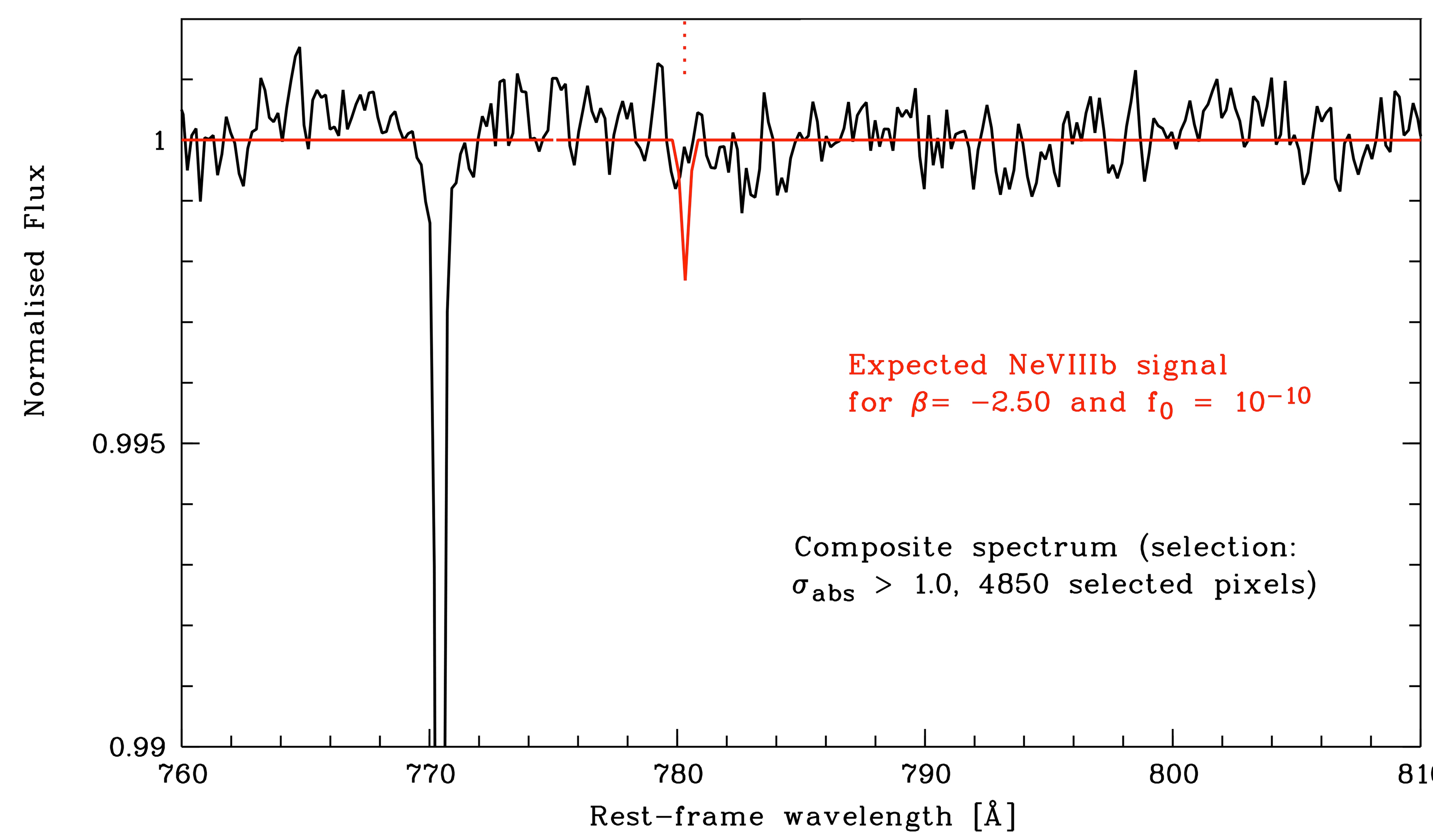

Fig. 1 Composite spectrum in the absorber restframe resulting from the selection of 4850 individual pixels in all of the 25 COS QSO sightlines (solid black curve). Note the scale for flux: the S/N/pixel reaches values > 1000. Shown in red is the expected signal at the location of the weaker doublet member NeVIIIb, derived by averaging over 100 sets of model spectra for one particular assumption about the underlying NeVIII absorber population.

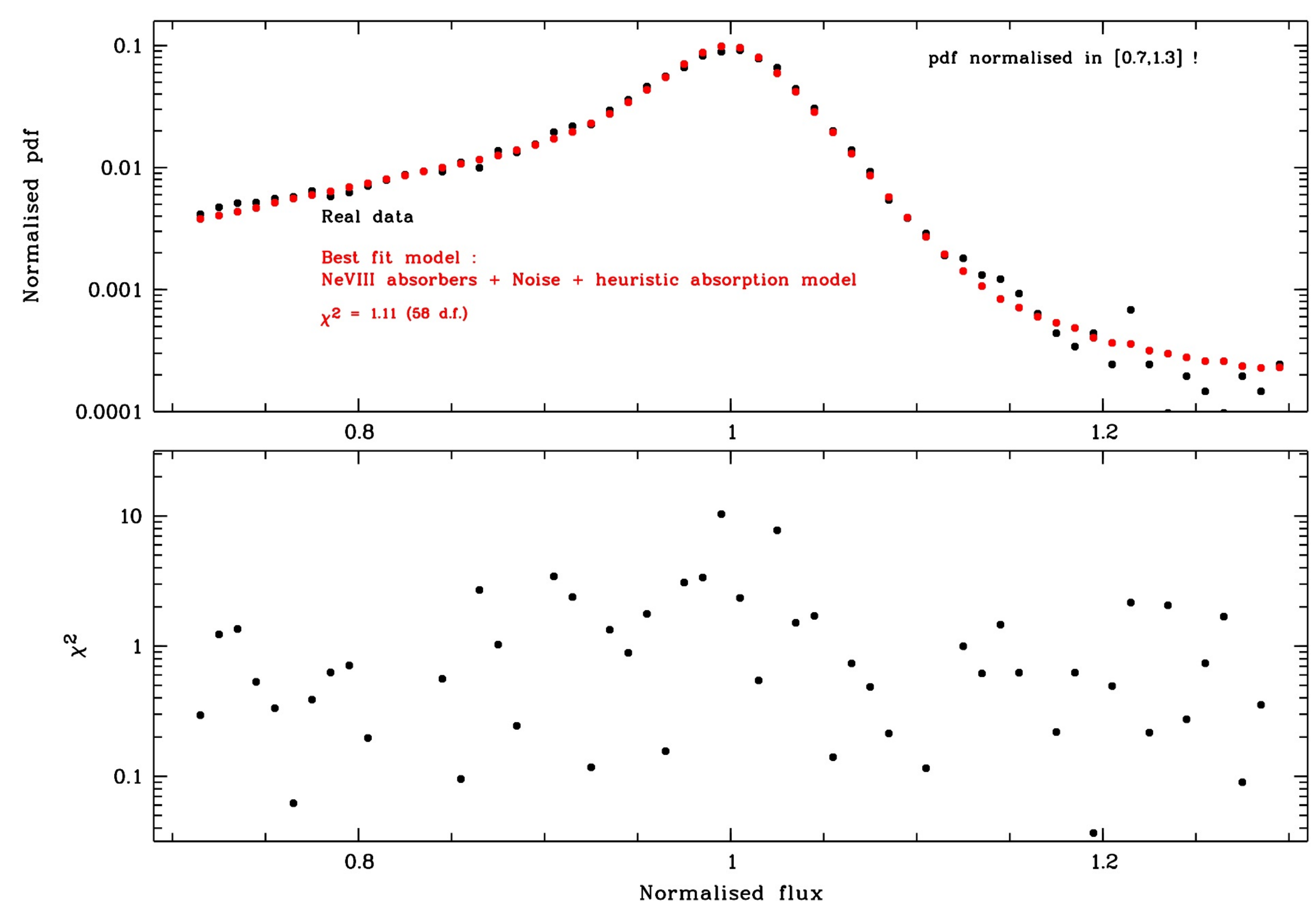

Fig. 2 An example of fitting the non-NeVIII absorption. Shown as black points is the pdf of the flux for real data. The red points show the pdf for a particular set of mock spectra after all three components have been added (NeVIII absorption ; additional non-NeVIII absorption using a purely heuristic exponential distribution in optical depth ; and the appropriate noise assuming Gaussianity in the real data). After finding a suitable model in this fashion, the expected signal strength at NeVIIIb is estimated by running the same selection process on the mock dataset to determine completeness and purity.

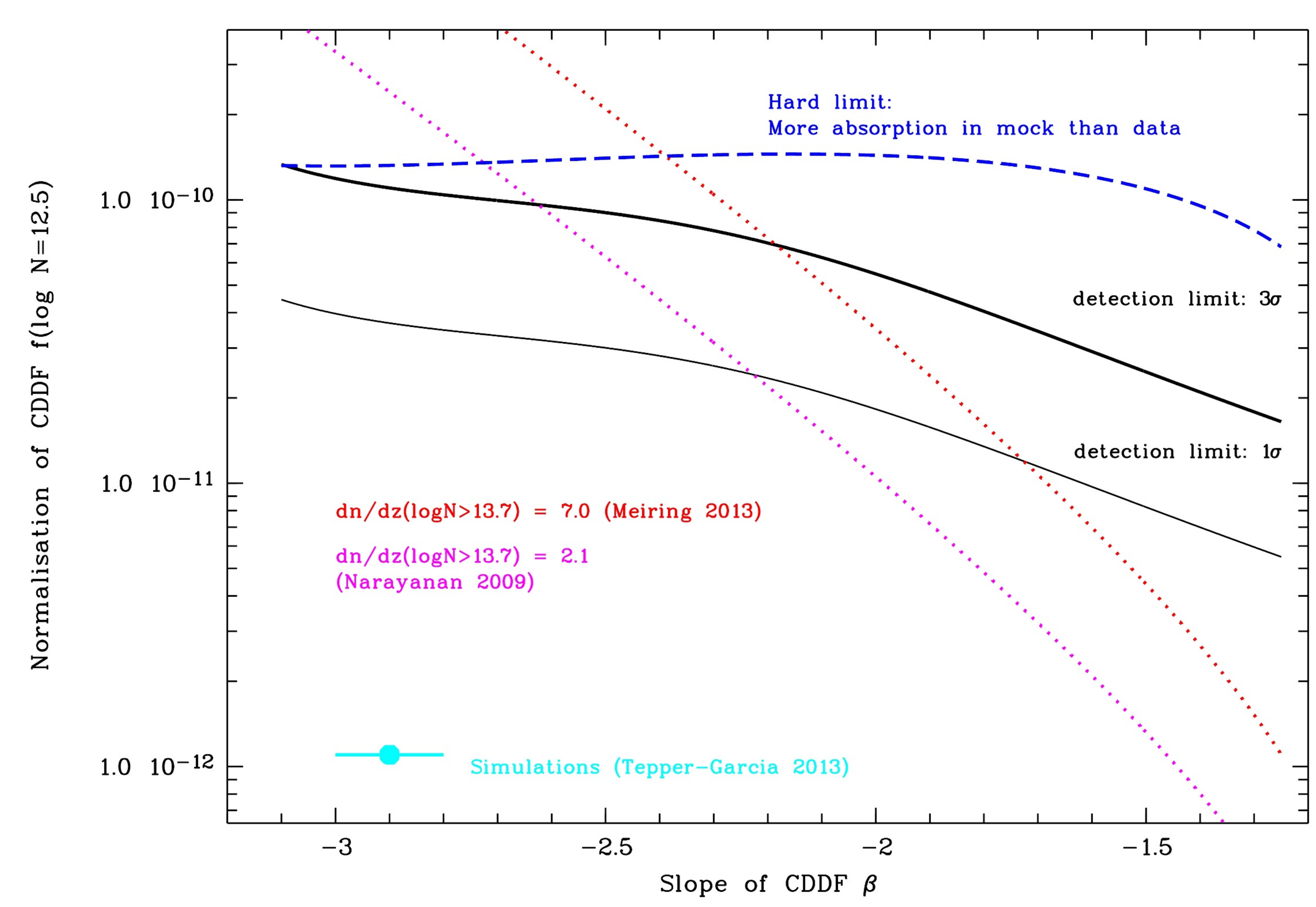

Fig. 3 The significance of a non-detection of NeVIIIb in our composite spectra. The thick solid black curves represent the 3σ and 1σ detection limits, derived by comparing the expected signal strength at NeVIIIb from the models with the noise in the real composite (see Fig. 1). The dotted blue line indicates the location above which there is already more absorption in the mock spectra **from NeVIII alone** than in the real data. The dotted lines show the extrapolation of two observed scenarios for strong NeVIII absorbers into the lower column density regime probed by our approach. The cyan datapoint (with errorbar for the slope) represents the scenario in state-of-the-art hydrodynamical simulations (Tepper-Garcia 2013).

References :
Savage et al. 2005, 2011a; Naryayanan et al. 2009, 2011, 2012; Tripp et al. 2011; Meiring et al. 2013, Hussain 2015), Oppenheimer 2013, Tepper-Garcia 2013.